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CONTENTS

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● **Lieut. Frank D. Klein** *after learning to fly as an Air Corps reserve officer, tried to settle down as a chemical engineer. But having been bitten by the flying bug, he decided to join the regular Army Air Corps. After two years as an engineering officer at Selfridge Field, Mich., he took the one-year graduate course at the Air Corps Engineering School, Wright Field, Dayton. He then specialized in aircraft fuels and lubricants, and is now in charge of development of fuels, lubricants, and cold weather engine operation for the Air Corps. He was born in Boston and graduated from M.I.T. in 1925.*

● **John M. Orr** *has been in Pittsburgh during his entire business life. Graduating from the Division of Industries, Carnegie Institute of Technology in 1915, he went to work for the Duquesne Light Co., left in 1920 to spend 7 years as assistant general manager of the United Electric Light Co.*

(Continued on page 22)

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Slow Motion Shows Knocking and Non-Knocking Explosions

By Lloyd Withrow and Gerald M. Rassweiler
Research Laboratories Section, General Motors Corp.

PREVIOUS studies of flame propagation in a gasoline engine have suffered from the handicap that only a partial view of the combustion space was obtained. This disadvantage has now been overcome by covering the whole top of a single-cylinder ell-head engine with a quartz plate so that an unobstructed view of the combustion-chamber is allowed.

To record, at known intervals, the progress and shape of the flame fronts a special camera has been built which photographs 30 individual pictures of a single explosion. Simultaneously, a pressure-time card is recorded. The interval between pictures is 2.4 crankshaft degrees; consequently, 5000 pictures per sec. are photographed at an engine speed of 2000 r.p.m.

These photographs may be studied individually or projected as "slow-motion" movies which show the ignition spark, the spread of the flame through the charge, and the gas movements behind the flame.

Pictures of non-knocking and knocking explosions are presented. The latter reveal in a most striking manner the occurrence of spontaneous ignition in sections of the charge well ahead of, and completely separated from, the advancing flame front.

FOR studying the flame propagation within a gasoline engine several different methods have been used. These methods have consisted of such procedures as the analysis of gas samples removed from the combustion-chamber by special, quick-acting sampling valves[1], as the photography of time-displacement records of flame motion in single-engine explosions[2], as visual and photographic observations through small windows in the top of an engine[3], and as observations of the ionization at various points in the combustion chamber[4].

When using any one of these experimental methods, the engine explosion can be examined only at a few definite points in the combustion space or, at best, in certain limited areas; hence, it has not been possible to obtain detailed information about the flame propagation throughout the entire combustion space in any single engine. Overcoming this difficulty required the solution of two problems: first, the construction of an engine fitted with a window that allows an unobstructed view of the entire combustion space; and second, the design and construction of a high-speed motion-picture camera that records the phenomena taking place within this combustion space.

Apparatus

In approaching the problem of obtaining an unobstructed view of the combustion-chamber of an operating gasoline engine, one is faced with several difficulties. First, the window must withstand the high temperatures developed by the flame in direct contact with its inner surface. This requirement influences not only the choice of window material but also the method of mounting it. Second, the window must withstand a force (in the present engine) of approximately 2.50 tons on its unsupported area. Third, a gas-tight seal must be made between the engine and the window without putting undue strain upon the window. Fourth, the window must be readily removable for cleaning.

Fig. 1 illustrates the arrangement finally adopted. Fused

[This paper was presented at the Semi-Annual Meeting of the Society, White Sulphur Springs, West Va., June 2, 1936.]

[1] See *Industrial and Engineering Chemistry,* September, 1930, pp. 945-951; "Following Combustion in the Gasoline Engine by Chemical Means", by Lloyd Withrow, W. G. Lovell, and T. A. Boyd. See also N.A.C.A. 1933 Technical Note No. 454; "The N.A.C.A. Combustion-Chamber Gas-Sampling Valve and Some Preliminary Test Results", by J. A. Spanogle and E. C. Buckley. See also Philosophical Transactions, the Royal Society, 1935, pp. 433-521, Vol. 234; "Estimation of the Combustion Products from the Cylinder of the Petrol Engine and Its Relation to Knock", by A. Egerton, F. L. Smith, and G. R. Ubbelohde.

[2] See *Industrial and Engineering Chemistry,* May, 1931, pp. 539-547; "Photographic Flame Studies in the Gasoline Engine", by Lloyd Withrow and T. A. Boyd. See also S.A.E. TRANSACTIONS, February, 1934, pp. 59-62; "A New Instrument Devised for the Study of Combustion", by C. F. Taylor, C. S. Draper, E. S. Taylor, and G. L. Williams. See also *The Automobile Engineer,* August, 1934, pp. 281-284; "Engine Knock"; and October, 1934, pp. 385-388; "Two Knocks in a Single Explosion"; both by Lloyd Withrow and Gerald M. Rassweiler.

[3] See the *Journal of the Institute of Petroleum Technologists,* 1930, pp. 756-776; "Flame Propagation in a Side Valve Petrol Engine", by H. S. Glyde. See also N.A.C.A. 1931 Technical Report No. 399; "Flame Movement and Pressure Development in Engine Cylinder", by Charles F. Marvin, Jr., and Robert D. Best. See also S.A.E. TRANSACTIONS, November, 1934, pp. 391-398; "Observations of Flame in an Engine", by Charles F. Marvin, Jr.

[4] See S.A.E. TRANSACTIONS, January, 1934, pp. 17-24; "Engine-Cylinder Flame Propagation Studied by New Methods", by Dr. Kurt Schnauffer. See also *Automotive Industries,* March 2, 1935, pp. 324-329; March 9, 1935, pp. 354-357; March 16, 1935, pp. 394-397; "Factors Controlling Engine Combustion", by Hector Rabezzana and Stephen Kalmar; also April 27, 1935, pp. 583-584; "Engine-Knock Characteristics Studied by Ionized-Gap Method", by William A. Mason and Kenneth M. Brown.

quartz was chosen as a window material because previous experience with small windows had shown that this material, when properly mounted, withstands engine-flame temperatures satisfactorily. In the present case, the window is a fused-quartz plate, 5¼ x 4 x ¾ in. in size. This plate is cemented into a heavy invar frame shown at the upper left in Fig. 1. Owing to the fact that the coefficient of expansion of invar increases very rapidly above 200 deg. fahr., the window frame is water-cooled so that its expansion remains comparable to that of the quartz when the engine is operating. The lower part of Fig. 1 is a photograph of the cylinder-block and the two clamps that are drawn down by means of the nut and yoke to fasten the window in place. Since the lower surface of the window and the window frame is flat, the sidewalls of the combustion space are cast integrally with the cylinder-block.

Some difficulty was experienced in sealing the window frame to the cylinder-block without cracking the window because the cylinder-block changed its shape slightly when the engine heated up. The strain necessarily introduced to make a gas-tight seal with a flat cylinder-head gasket on the uneven surface was great enough to break the window, even though the window frame was very rigid.

The combustion space is now sealed with a narrow copper-asbestos gasket, having a section ⅛ in. thick and ¼ in. wide. The gasket fits in a tapered groove that is machined both in the cylinder-block and in the window frame as shown in Fig. 1. The depth of this groove varies from 0.040 in. at the inner edge to 0.003 in. at the outer edge so that the gasket is self-sealing. When the gasket is used alone, a dead space appears between a portion of the lower surface of the window and the top of the cylinder-block. Unless this dead space is

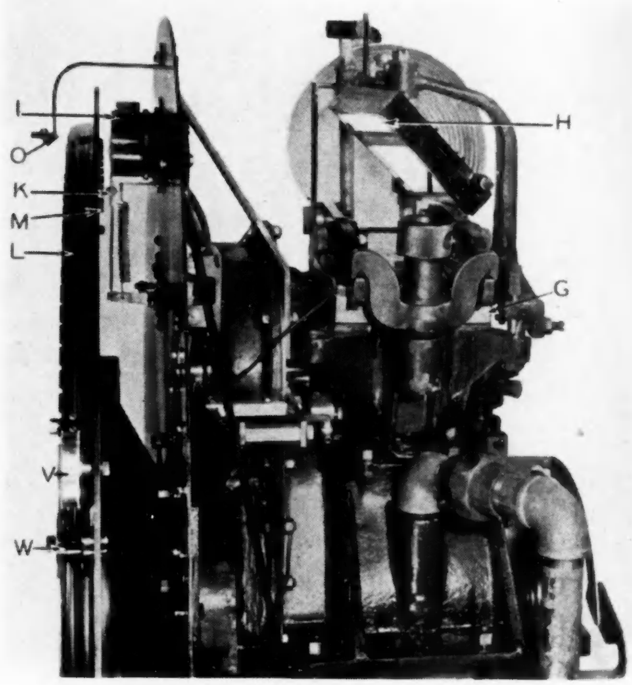

Fig. 2 – High-Speed Motion-Picture Camera Mounted on Engine

G – window retainer	*K* – shutter
H – mirror	*L* – rotating disc
I – field lens	*V* – metering-sprocket
O – focal-plane shutter	*W* – take-up spool

filled, some of the charge burns in it, and the entire combustion process cannot be photographed. In the present experiments this dead space was filled with a copper gasket of known thickness, the window being pulled down to give from 0.001 to 0.003 in. clearance so that the entire explosion occurs beneath the clear section of the window. The compression ratio under these conditions is 4.7:1. The bore and stroke are 2⅞ and 4¾ in., respectively.

To study the combustion phenomena in this engine, there has been built a special high-speed motion-picture camera, designed to comply with the following major requirements:

First, the number of pictures photographed per second must be extremely high if, during a single explosion, sufficient pictures are to be obtained to allow a careful study of the flame propagation. On this account, ordinary motion-picture cameras, which employ intermittent film motion, are entirely out of the question. Second, because all of the light available for photographing the flames comes from the flames themselves, the optical system must be fast and efficient, and the exposure of each picture must be comparable to the interval between pictures. Third, the pictures must not be so small that details of flame structure are lost. Fourth, the angular position of the crankshaft at which each picture is taken must be known accurately.

To meet the above requirements, the camera shown in Fig. 2 has been constructed. At the right side of the photograph is the cylinder-block of the engine with the quartz window mounted in place. The light from the flames in the engine comes up through the window, is reflected by the mirror *H* into the stationary lens *I*, passes through the moving lenses *M*, and is again reflected up to the film which is carried inside the overhanging rim of the disc *L*. The disc is rotated at engine speed by the crankshaft.

As each of the 30 small lenses *M* passes the stationary

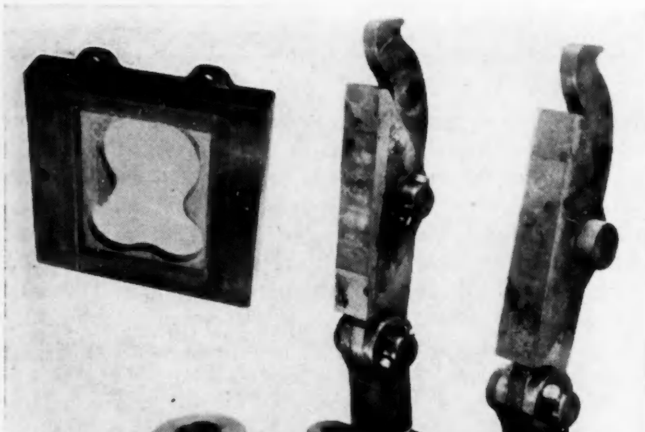

Fig. 1 – Cylinder-Block and Window Used for Obtaining an Unobstructed View of the Combustion in a Gasoline Engine

lens, a separate picture of the flames in the engine is recorded. With this arrangement of the optical parts, the image formed on the film by the lenses moves with the film during the exposure of each picture. *K* is a shutter that opens for one engine explosion only. The "focal-plane" shutter *O* controls the exposure time of each picture. Extra film is stored on the spool *W* and, by means of the metering device *V*, a fresh piece of film can be pulled into place after each set of pictures is photographed. When in operation, the camera is covered with a light-tight housing. A more detailed description of the camera and its action has already appeared in the literature[5]. Hence, further details will not be included here.

Fig. 3 presents a typical set of flame pictures showing the flame propagation in a single explosion occurring when the engine was running 2000 r.p.m. on a non-knocking fuel, a blend of gasoline and benzene having been used for fuel in this instance because of the high luminosity of benzene flames. The spark advance was 28 deg. and the mixture, which contained about 80 per cent of the theoretical air, was slightly richer than that required for maximum power. On account of the unusually high wind resistance of the lens disc, the output of the engine, even though it was running at full throttle, was not sufficient to rotate the disc at 2000 r.p.m.; consequently, it was necessary to supply the additional power with the dynamometer.

As is indicated by the numbers at the left-hand ends of the five rows of six pictures each, the picture sequence when considered chronologically is to be read from left to right and from top to bottom of Fig. 3. Below each flame photograph is the crankshaft angle at which the focal-plane shutter stopped the exposure, the minus (—) signs denoting angles before top dead-center and the plus (+) signs denoting angles after top dead-center. The duration of each exposure (not to be confused with the time interval between exposures) was 2.2 crankshaft deg.; for example, picture No. 1 was exposed from 31.2 deg. before, until 29 deg. before top dead-center. The time interval between each exposure was 2.4 deg. of crankshaft revolution which, at 2000 r.p.m., amounted to 1/5000 sec.; thus, the entire set of 30 pictures was exposed in 0.006 sec.

In photographing this explosion, sufficient light from an external source was thrown down on top of the engine to show dimly the piston and the valves in the background. These parts of the engine can be seen best in photographs

[5] See *Industrial and Engineering Chemistry,* June, 1936, pp. 672-677; "High-Speed Motion Pictures of Engine Flames", by Gerald M. Rassweiler and Lloyd Withrow.

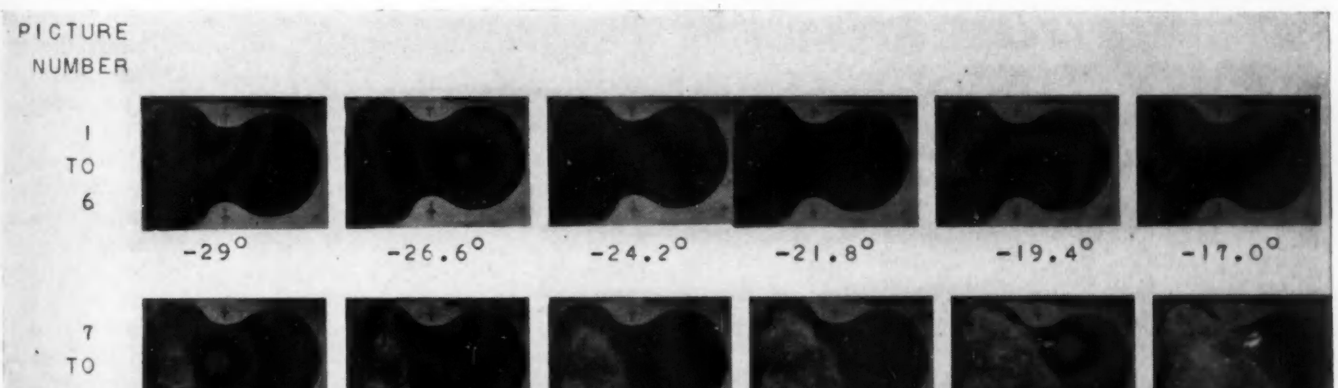

Fig. 3 – A Non-Knocking Explosion in a Gasoline Engine Running at 2000 R.P.M.

Nos. 25 to 30 in Fig. 3. The intake valve is in the upper left-hand corner of each picture, and the exhaust valve is in the lower left-hand corner. In Fig. 1 it was seen that the spark-plug terminals were located near the end wall about midway between the two valves and between the floor and ceiling of the combustion space.

The ignition spark occurred in the second picture, which was exposed from 28.8 deg. before until 26.6 deg. before top dead-center. The spark continued to oscillate during the exposures of pictures Nos. 2 to 5, inclusive. In the fifth picture the spark was surrounded by a small globule of flame about ½ in. in diameter. During the exposure of pictures Nos. 4 to 9, inclusive (from 24 deg. before until 9.8 deg. before top dead-center), this globule of flame increased in size in a fairly regular manner showing a slight tendency to travel faster toward the exhaust valve than toward the intake valve.

In the tenth picture the flame front began to spread through the throat of the combustion space and, at this time, the flame propagated faster through the portion of the combustion-chamber located near the bottom of the picture than through that portion near the top of the picture. The increased flame velocity along this one side of the combustion-chamber continued during the rest of the explosion with the result that the last part of the charge to burn was located in the portion of the combustion-chamber near the upper side of the picture. It is believed that this unsymmetrical flame propagation was caused by mass movements of the charge induced during the intake stroke.

Just after the flame front reached the edge of the piston, in picture No. 11, a bright spot made its appearance close to the edge of the piston and thereafter increased in size until it was the most prominent feature shown in pictures Nos. 25 to 30. This brilliant luminosity was produced by incandescent carbon left by partially burned and decomposed lubricating oil. Apparently, this oil was thrown up into the combustion-chamber by the upward motion of the piston because the spot first appeared before top dead-center. In pictures photographed after top dead-center there appeared, close to the cylinder walls, additional luminosity which was probably due to incandescent carbon formed from oil left on the cylinder walls as the piston moved downward. The incandescent carbon is of particular interest because, as will be shown later, it allows the gas movements behind the flame front to be followed.

At the forward edges of the flames in each of pictures Nos. 13 to 22 inclusive, well-defined regions appear. Such a region is shown particularly well on picture No. 17, for example. Behind this flame front is a less luminous region and, near the spark-plug and the exhaust valve, is a region of high luminosity called the afterglow.

There is already considerable evidence to indicate that the gasoline is burned in the flame front in so far as permitted by the available oxygen and by chemical equilibrium under the prevailing conditions. This evidence consists of experiments with the sampling valve[6], which showed that the free oxygen at a point in the combustion-chamber disappeared almost as soon as the flame arrived; and also of experiments with the spectrograph[7], which showed that the spectrum of the flame fronts was characteristic of burning hydrocarbons while the spectrum of the afterglow was characteristic of carbon dioxide. If the gasoline is burning in the flame front, then the flame-front portion of the charge should expand, thereby compressing the gases both ahead of, and behind, the flames.

Referring again to Fig. 3 and examining the luminous cloud of incandescent carbon, it will be noted that in pictures Nos. 13 to 18 the luminous area was pushed backward toward the spark-plug by the expansion of the burning gases in the flame front. In pictures Nos. 19 to 30, the motion of the cloud of incandescent carbon was reversed, the gas being pulled into the cylinder by the descent of the piston. The point of reversal of this motion in picture No. 19 occurred at the time of peak pressure in this explosion. At peak pressure a considerable portion of the charge was still unburned. In fact, combustion was not completed until the twenty-fifth or twenty-sixth picture, which was approximately 15 deg. of rotation past the time of peak pressure.

The afterglow in Fig. 3 is noteworthy. In pictures Nos. 13 to 18 the afterglow increased rapidly in brilliance in those portions of the charge that burned first and reached its maximum intensity at, or slightly before, peak pressure. The greater intensity of the afterglow over the exhaust valve as compared with its intensity over the intake valve in these pictures is probably connected with the mass movements of the charge already mentioned in connection with the unsymmetrical flame propagation. As the pressure decreased during the exposure of pictures Nos. 20 to 30, the afterglow decreased rapidly in intensity.

Now, in connection with the behavior of the afterglow, it is interesting to consider the temperature changes which occur in those portions of the charge that burn first, these temperatures having been measured by the use of the sodium-line reversal method[8]. Such measurements have shown that the temperature in the gases that burn first continues to increase until slightly before maximum pressure. The continued temperature increase results from compression of the initially burned gas during the combustion of the remainder of the charge. At the end of combustion, the temperature in the gases that were burned first is higher than that in the gases that burn last. Simultaneously, as shown by pictures Nos. 27 to 30 in Fig. 3, the gases that were burned first radiate light of greater intensity than those gases that burned last. It therefore appears that the changes in the intensity of the afterglow and in the magnitudes of the gas temperatures are closely related.

Fig. 4 portrays another non-knocking explosion, with the engine running now at a lower speed than was employed for Fig. 3. When the pictures in Fig. 4 were exposed, the engine was operating on iso-octane at a speed of 900 r.p.m., with a spark advance of 25 deg. and with about 15 lb. of air per lb. of fuel in the mixture. The interval between pictures was 2.40 crankshaft deg. as before but, on account of the lower engine speed, the time interval between pictures was 1/2250 sec. instead of 1/5000 sec.

In Fig. 4 the ignition spark appeared during the exposure of the third picture, is absent from the fourth, and reappeared in the fifth. Pictures Nos. 7 to 11, which were exposed between 16.8 deg. before, and 5 deg. before top dead-center, show the flame front propagating steadily in a manner very similar to corresponding pictures in Fig. 3. In pictures Nos. 10, 11, and 12 the flame front propagated through the throat of the combustion space. Here the behavior of the flame front in this explosion was quite different from the explosion

[6] See *Industrial and Engineering Chemistry*, September, 1930, pp. 945-951; "Following Combustion in the Gasoline Engine by Chemical Means", by Lloyd Withrow, W. G. Lovell, and T. A. Boyd.

[7] See *Industrial and Engineering Chemistry*, July, 1931, pp. 769-776; "Spectroscopic Studies of Engine Combustion"; also May, 1932, pp. 528-538; "Emission Spectra of Engine Flames"; both by Lloyd Withrow and Gerald M. Rassweiler.

[8] See S.A.E. Transactions, April, 1935, pp. 125-133; "Flame Temperatures Vary with Knock and Combustion-Chamber Position", by Gerald M. Rassweiler and Lloyd Withrow.

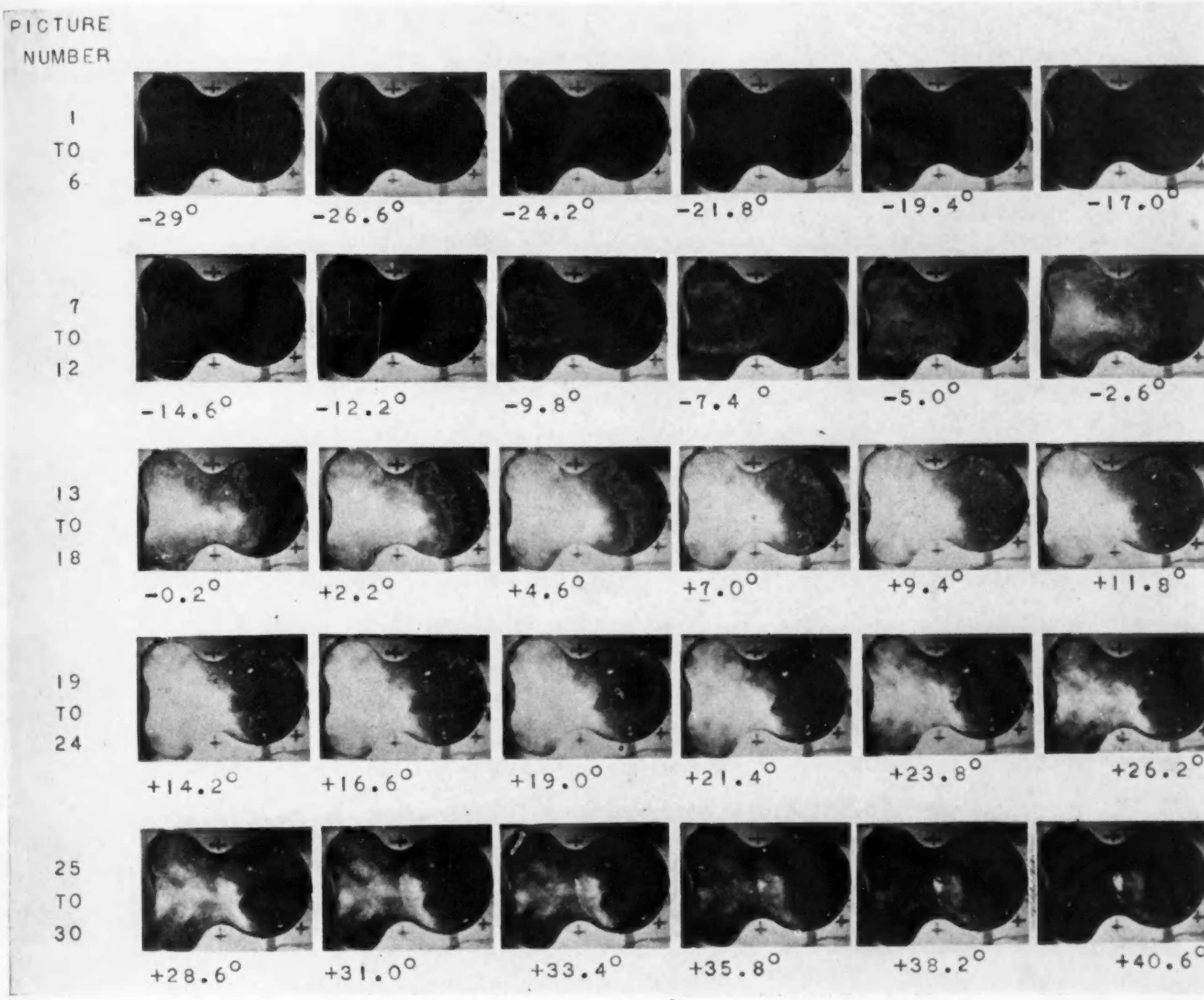

Fig. 4 – A Non-Knocking Explosion in a Gasoline Engine Running at 900 R.P.M.

photographed at 2000 r.p.m. The mass movements of the charge were sufficient to alter slightly the direction of flame propagation, but this effect was not nearly so pronounced as in Fig. 3. Furthermore, there was no evidence of oil being thrown up into the charge by the piston. (See pictures Nos. 11, 12, 13, 14, and 15.) The charge over the intake valve was completely inflamed in picture No. 13, about 2 deg. before completion of inflammation over the exhaust valve. During the exposure of pictures Nos. 15 to 21 inclusive, the flame front passed over the piston completing the inflammation at about 21 deg. past top dead-center.

In the explosion portrayed in Fig. 4, maximum pressure was reached at about 16 deg. past top dead-center. The afterglow appears to have reached its maximum brilliance slightly before maximum pressure, as was also the case in Fig. 3. The forward boundary of the afterglow was not quite symmetrical, and the glowing gases showed a slight drift toward the exhause valve, both of these phenomena probably being produced by the same gas movements that were responsible for the slight distortion in flame propagation.

Arranged in Fig. 5 in the same sequence as the sets of pictures in Figs. 3 and 4 is a series of pictures of a single explosion exposed with the engine running at 900 r.p.m. on a gasoline having an octane number of 48. When the engine was operated on this fuel, it knocked moderately hard. The mixture contained approximately 15 lb. of air per pound of fuel, and the spark advance was set at 25 deg. Thus, with the exception of the presence of knock, the engine conditions were very similar to those maintained during the exposure of the pictures of Fig. 4.

Fig. 5 shows the ignition spark in the third picture. On the original negative, a small ball of flame can be seen growing steadily in size in pictures Nos. 5 to 7 inclusive but, on the prints, flame can first be discerned on the eighth picture. At this time the flame envelope was about 1 in. across. This flame continued to propagate over the valves and out toward the piston in pictures Nos. 8 to 11 inclusive. Pictures Nos. 12 to 15 inclusive, which were exposed between 4.8 deg. before top dead-center and 4.6 deg. past top dead-center, are most interesting because they show the behavior of the flame just before, during, and after, the occurrence of knock. In the twelfth picture the flame front was over the inside edge of the piston, and the combustion process appeared to be normal in every respect. It will be noted that the flame front was at approximately the same position as in the corresponding picture of non-knocking combustion in Fig. 4. But in the

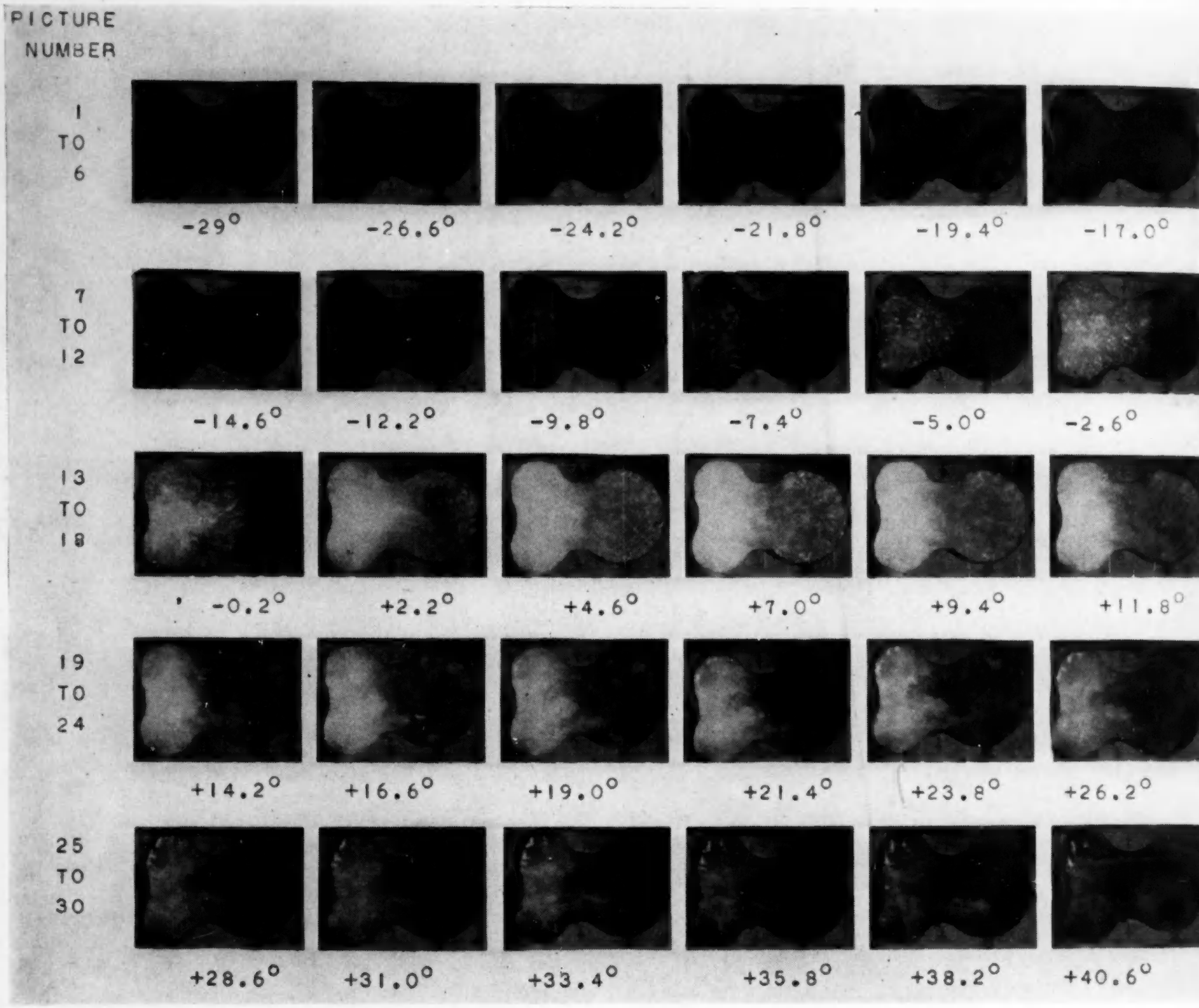

Fig. 5 – A Knocking Explosion in a Gasoline Engine Running at 900 R.P.M.

thirteenth picture in Fig. 5, auto-ignition occurred near the end of the combuston space over the piston at a point well separated from the normal flame front. This auto-ignition is the first evidence of knock in this explosion. In picture No. 14, exposed less than 1/2000 sec. later, the spontaneous inflammation has spread all through the remaining charge except for a small dark area, which apparently is not quite inflamed and which lies just ahead of the original flame front. Most striking is the fact that the form and position of this original flame front are not greatly changed from picture No. 13.

Thus, in this case and perhaps in all knocking explosions, the knock is definitely not a result of a sudden increase in velocity of the advancing flame. While this point has been made before in connection with time-displacement records of knocking explosions[9], it has never been so convincingly demonstrated as in Fig. 5.

[9] See *Industrial and Engineering Chemistry*, May, 1931, pp. 539-547; "Photographic Flame Studies in the Gasoline Engine", by Lloyd Withrow and T. A. Boyd.

[10] See *Industrial and Engineering Chemistry*, August, 1933, pp. 923-931; "Absorption Spectra of Gaseous Charges in a Gasoline Engine"; also December, 1933, pp. 1359-1366; "Spectrographic Detection of Formaldehyde in an Engine Prior to Knock"; also December, 1934, pp. 1256-1262; "Formaldehyde Formation by Pre-Flame Reactions in an Engine"; all by Lloyd Withrow and Gerald M. Rassweiler.

Although pictures Nos. 12 in Figs. 4 and 5 appear quite similar, it is not to be inferred that all conditions in the engine were the same when the two pictures were taken. Under knocking conditions (Fig. 5), chemical reaction was already under way in the dark non-inflamed gases ahead of the flame. Evidence of such reactions has been obtained[10] by means of absorption spectra taken through the non-inflamed charge just prior to knock.

Pictures of other explosions, which occurred under the same engine conditions as those maintained during the recording of the explosion reproduced in Fig. 5, show differences in the phenomena of auto-ignition and of the behavior of the gases behind the flame front at the time of knock. To give some indication of the nature of these differences, there are compared in Fig. 6, pictures that show the occurrence of knock in six different explosions. While photographing each of these explosions, the engine conditions were maintained as nearly like those outlined in the description of Fig. 5 as was practicable.

Each horizontal strip of pictures in Fig. 6 shows the occurrence of knock in a single explosion, the set of pictures labeled explosion *A* being pictures Nos. 12 to 17 inclusive, of Fig. 5. The numbers of the pictures taken from each of the

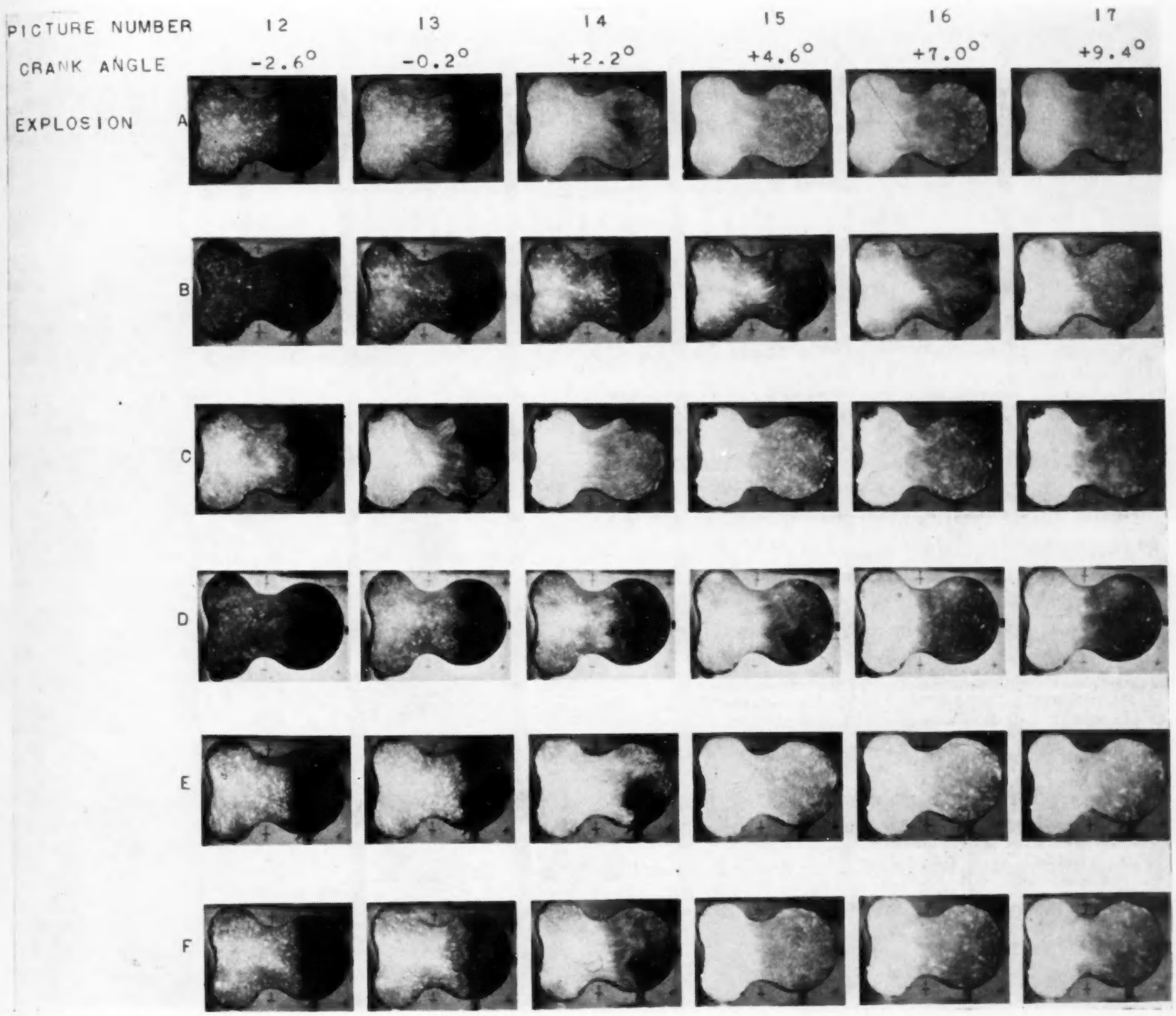

Fig. 6 – Occurrence of Knock in Six Different Explosions Photographed under Similar Engine Conditions

explosions are shown at the top of Fig. 6 and, just beneath the picture numbers, are the respective angles of revolution at which the shutter closed for each individual exposure.

On comparing the sets of pictures in Fig. 6, it is at once apparent that knock did not occur at the same crankshaft angle of revolution in all six explosions. In each case picture No. 12 was exposed between 4.8 and 2.6 deg. before top dead-center. At this time explosion *C* showed some evidence of the inception of auto-ignition in the lower right hand corner of picture *C*-12, but none of the other explosions gave any indications of the beginnings of auto-ignition. During the next 2.4 crankshaft deg. auto-igition appeared distinctly in explosions *A* and *C* as is evidenced by pictures Nos. 13 of these explosions. When the exposure of pictures Nos. 14 was completed at 2.2 deg. after top dead-center, there were indications of auto-ignition in all six explosions. In pictures Nos. 15 for which the exposures ended at 4.6 deg. after top dead-center, inflammation appears to be complete in explosions *A* and *C*, is almost at an end in explosions *E* and *F*, and is well under way in explosions *B* and *D*, requiring about 5 more crankshaft deg. for completion in explosion *B* (pictures Nos. 16 and 17) and about 2 more crankshaft deg. for completion in explosion *D*.

It will be noted also that auto-ignition did not begin at the same position in the combustion space in every explosion, the variation being particularly striking in explosions *A*, *B*, and *C*. Furthermore, in some of the pictures, flame appeared at several points in the charge even after the knock was well under way. For example, in picture No. 14 of explosion *F*, the flame has started to spread from two points distinctly separated from both the original flame front and the area of initial spontaneous ignition. These observations are significant because, if knock were produced by a given hot-spot or hot-spots on the combustion-chamber walls, auto-ignitions should always occur at the same position or positions in consecutive explosions.

The possibility of following the movements of the gases behind the flame front by observing the motion of a luminous cloud of incandescent carbon particles suspended in the inflamed gases was mentioned in the description of Fig. 3. Similarly in Fig. 6, the gas movements behind the flame

(Continued on page 312)

Future Possibilities of 100-Octane Aircraft-Engine Fuel

By Lieut. F. D. Klein
U.S. Army Air Corps

INCLUDED in this paper are: Comparative performance of various types of fuels in high-output, single-cylinder liquid-cooled engine, and comparative performance of 100-octane toluene blend and iso-octane blend relative to 92-octane Army method regular gasoline in full-scale engine with two-speed supercharger and normal compression ratio.

Endurance tests scheduled in Cyclone and two-row Wasp with 8:1 compression ratio and very low specific fuel consumption.

Military present and contemplated future use of this fuel and its commercial possibilities.

Possible means for increasing available supply.

Availability of unleaded high-antiknock fuels and leaded fuels superior to 100-octane fuel.

UNTIL about 1928, aircraft-engine fuel had an antiknock value of about 50-55 octane. Development of suitable knock-test methods and investigation of engine performance with higher antiknock leaded fuels led to the adoption of the present Air Corps standard fuel having an antiknock value of 92 octane by the Army method of knock test, and having normally a value of about 87 octane by the A.S.T.M. method. This fuel is now in general use in this country and, by development of engines to utilize its inherent advantages, an increase of about 33 1/3 per cent in power output per unit weight has been obtained over that possible with earlier type engines. Antiknock values higher than the present standard until recently have not appeared practicable because of limited availability and prohibitive cost of such fuels.

Developments of the fuel industry made possible early in 1934 the production of commercial iso-octane on a large scale, and at a cost sufficiently low to assure a promising future for iso-octane blends having an antiknock value considerably above that available for service use in the past. Full-scale engine tests conducted by the Air Corps in 1934 and reported by the author[1] showed that an increase of 15 to 30 per cent in power output is possible with Army 100-octane fuel over that obtainable with Army 92-octane fuel. For maximum output, high degree of supercharge without the use of a very high compression ratio is desirable. To obtain maximum economy, high compression ratio is essential, and degree of supercharge need only be great enough to provide the necessary power for take-off and altitude performance. Results of high compression ratio tests conducted by the Wright Aeronautical Corp. in a Cyclone engine, which have been reported by Raymond W. Young[2], indicate that specific fuel consumptions as low as 0.34 lb. per b.hp-hr. can be obtained in the cruising range without excessive engine temperatures by the use of 100-octane fuel. This performance represents a saving of about 20 per cent over the best economy obtainable with Army 92-octane fuel.

It cannot be stressed too greatly that fuel and engine development are so closely allied that improvements in economy and output over a period of years must be attributed both to the better fuel available and to the improved design of engines. Increases in output with certain given engines due entirely to the use of better fuel were demonstrated by the author[1] in comparing Army 92-octane with Army 100-octane fuel. On the other hand present engines, which are designed to operate satisfactorily at full throttle at sea level using Army 92-octane fuel, would not be expected to show any appreciable increase in power output by the use of Army 100-octane fuel, although reduction in fuel consumption or in cylinder temperature could be obtained in many cases.

To provide improved performance with a given grade of fuel, many engine developments have proved effective, one outstanding example being the increase in cooling-fin area of the Cyclone cylinders. It is worthy to emphasize that the use of high antiknock fuel will not insure good performance of all engines. An example of this condition is an engine now undergoing experimental tests at the Materiel Division. This engine is a radial air-cooled engine of conventional design except for high-turbulence pistons which were installed for experimental purposes. The engine has a compression ratio of 6.2:1, a blower-gear ratio of 12:1, and an impeller diameter of 8½ in. Operating at 2200 r.p.m. with Army 100-octane fuel, with an intake-air temperature of 74 deg. fahr. and an air-blast temperature of 63 deg. fahr., this engine delivers only 464 hp., equivalent to 125 lb. per sq. in. b.m.e.p.,

[This paper was presented at the Semi-Annual Meeting of the Society, White Sulphur Springs, West Va., June 5, 1936.]

[1] See the *Journal of the Aeronautical Sciences*, March, 1935, pp. 43-47; "Aircraft-Engine Performance with 100-Octane Fuel", by F. D. Klein.

[2] See S.A.E. TRANSACTIONS, June, 1936, pp. 234-256; "Air-Cooled Radial Aircraft-Engine Performance Possibilities", by Raymond W. Young.

the specific fuel consumption for maximum power being 0.49 lb. per b.hp-hr. At this output the engine is limited by moderate detonation, although the maximum cylinder-head and base temperatures are 420 deg. fahr. and 280 deg. fahr. respectively, which values are considerably lower than are normally experienced with detonation.

For comparison, a standard engine of the same displacement has delivered 510 hp., equivalent to 137 lb. per sq. in. b.m.e.p., with Army 92-octane fuel, and 620 hp., equivalent to 167 lb. per sq. in. b.m.e.p., with Army 100-octane fuel, with only light detonation being present. The limitation of the special engine is attributable in part to the high-turbulence pistons, but largely to the high temperature of the intake air out of the supercharger, which was found to be 221 deg. fahr., equivalent to a temperature rise in the supercharger of 147 deg. fahr.

From the foregoing paragraphs it is seen that improvements in either engine design or fuel alone can give increased performance. However, as long as development of both engines and fuels continues hand-in-hand as it has done in the past and is certain to do in the future, the maximum increases in performance can be expected from engines designed to operate with the highest antiknock fuels available, with credit due in part to the development of engines and in part to the development of fuels.

High-Output Single-Cylinder Tests

In order to determine the relative value of various types of high antiknock fuels in extremely high-output liquid-cooled engines, the Materiel Division in December, 1935, and January, 1936, conducted tests of many types of fuels in a single-cylinder liquid-cooled engine with a bore of 4⅝ in., a stroke of 5 in., and a compression ratio of 5.83:1. The tests were conducted at a speed of 2500 r.p.m., a jacket temperature of 250 deg. fahr., a spark advance of 30 deg., and a mixture temperature of about 50 deg. fahr. The engine was operated at full throttle, with the inlet-air pressure increased progressively until light detonation occurred at the air-fuel ratio giving maximum power. This inlet-air pressure was then held constant, and a mixture-control run made. The brake mean effective pressure was then determined covering a range of air-fuel ratios from maximum power to maximum economy.

Table 1

Power Plant Fuel Number	Octane Number	Description
Army 92-Octane	92	Regular Specification 2-95, Grade 92.
520	99½	Commercial iso-octane.
Army 100-Octane	100	Regular Specification 2-92, Grade 100
553	100	Iso-octane plus aviation naphtha plus iso-pentane plus 3 cc. $PbEt_4$ per gal.
520 plus 3 cc. $PbEt_4$	c.p. iso-octane plus 2 cc. $PbEt_4$	Commercial iso-octane plus lead.
556	92	Benzol plus California aviation gasoline plus 2.2 cc. $PbEt_4$ per gal.
520 plus 6 cc. $PbEt_4$	c.p. iso-octane plus 4 cc. $PbEt_4$	Commercial iso-octane plus lead.
552	97	Toluene plus low vapor pressure aviation natural gasoline plus iso-pentane plus 3 cc. $PbEt_4$ per gal.
554	99	Toluene plus benzol plus iso-pentane plus 3 cc. $PbEt_4$ per gal.

The fuels of most interest from a comparative standpoint, together with the Army octane number determined by the method covered in Specification 2-94, are given in Table 1.

The results of test are plotted on Fig. 1. It is to be noted that no detonation occurred with Fuels Nos. 552, 554, and 520 plus 6 cc. of lead, the output being limited only because of danger of mechanical failure. The difference in output shown for these three fuels has no significance since any one of the three might have exceeded the maximum of 520 lb. per sq. in. b.m.e.p. without detonation. This maximum brake mean effective pressure, which required 64 in. hg. boost (94 in. hg. absolute pressure), is the highest that has been obtained at the Materiel Division with a straight hydrocarbon fuel although, with longer stroke and lower compression ratio, this engine delivered 579 lb. per sq. in. b.m.e.p. with 75.8 in. hg. boost, with the assistance of water injection, as reported by Ford L. Prescott[3].

Output with regular Army 100-octane fuel is seen to be 22.7 per cent higher than with regular Army 92-octane fuel, which figure is in line with results of past full-scale tests. All fuels are seen to lie closely in the order of their Army octane ratings, with the exception of the three aromatic fuels, Nos. 552, 554, and 556, all of which are very much over-rated by this engine with respect to their Army octane ratings. Fuel No. 553, which is quite similar in composition to regular Army 100-octane fuel and has identically the same knock rating, delivers 6.4 per cent higher output, which difference

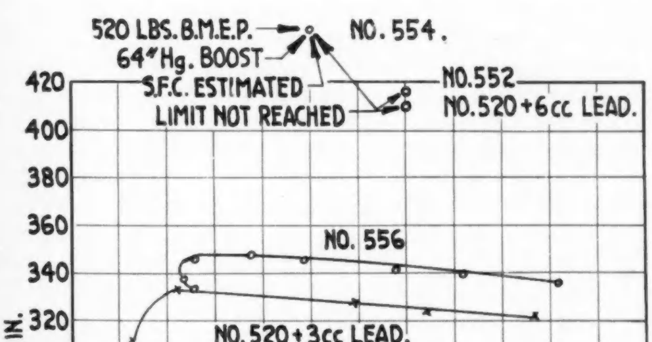

Fig. 1—High-Output Single-Cylinder Engine Tests
Bore, 4⅝ in.; stroke, 5 in.; r.p.m., 2500; jacket temperature, 250 deg. fahr.; spark advance, 30 deg.; compression ratio, 5.83:1; full throttle; mixture temperature, approximately 50 deg. fahr.

[3] See *Mechanical Engineering*, March, 1936, pp. 157-161; "Military Aircraft Engines of the Future", by Ford L. Prescott.

is attributable to lack of sufficient sensitivity of the Army knock-test method above 100 octane.

An interesting comparison can be drawn between the results for regular Army 92-octane fuel, iso-octane, and iso-octane plus lead, and the results obtained with similar fuels by the Lycoming Manufacturing Co.[4] using a different type of single-cylinder engine. In the Lycoming tests an intake-air temperature of 203 deg. fahr. was used, as compared with about 75 deg. fahr. intake-air temperature and 50 deg. fahr. mixture temperature in the Army tests. The specific fuel consumption for maximum power did not differ greatly for both series of tests, being 0.425 lb. per b.hp-hr. in the Lycoming and 0.443 lb. per b.hp-hr. in the Army tests in the case of iso-octane plus 3 cc. of lead. The relative results are tabulated in Table 2.

Table 2

Fuel	Relative Power, per cent Lycoming	Army
Army 92 octane	100	100
Iso-octane	117	120
Iso-octane plus 3 cc. $PbEt_4$	134 plus	155
Iso-octane plus 6 cc. $PbEt_4$	—	190 plus

These results show excellent agreement, particularly in view of the great difference in intake-air temperatures used. The Lycoming results indicate that iso-octane plus lead has decided possibilities for extreme outputs even when intercoolers are not provided; the Army results indicate that additions of lead in concentrations as high as 6 cc. per gal. are advantageous.

The results obtained on the Army high-output engine cannot be applied directly to predicting full-scale performance, particularly of highly supercharged air-cooled engines not equipped with intercoolers. Full-scale engine tests of the past have indicated that present knock-test methods rate highly aromatic fuels as closely in line with their multicylinder performance as can be expected in view of their marked difference in relative performance in various types of engines. It is therefore supposed that the extremely good performance of the aromatic fuels in the single-cylinder tests can be attributed largely to the low mixture temperature, which is known to favor such fuels.

The tests were mainly of a preliminary nature, to indicate the fuels of most value for further testing, although the results will bear some relation to performance of fuels in multicylinder liquid-cooled engines of the future, utilizing intercoolers. The Materiel Division plans to conduct additional tests of the most promising fuels in a highly supercharged single-cylinder liquid-cooled engine and a single cylinder of the conventional air-cooled type, each with variable mixture temperature; and also in full-scale multicylinder engines of the latest types.

Full-Scale Economy Tests

In order to obtain additional data on full-scale performance of Army 92-octane fuel and various types of 100-octane fuels with particular stress on economy of operation over the entire range, tests were scheduled in an R-1820 (Wright Cyclone) engine with standard 6.45:1 compression ratio and 11-in.

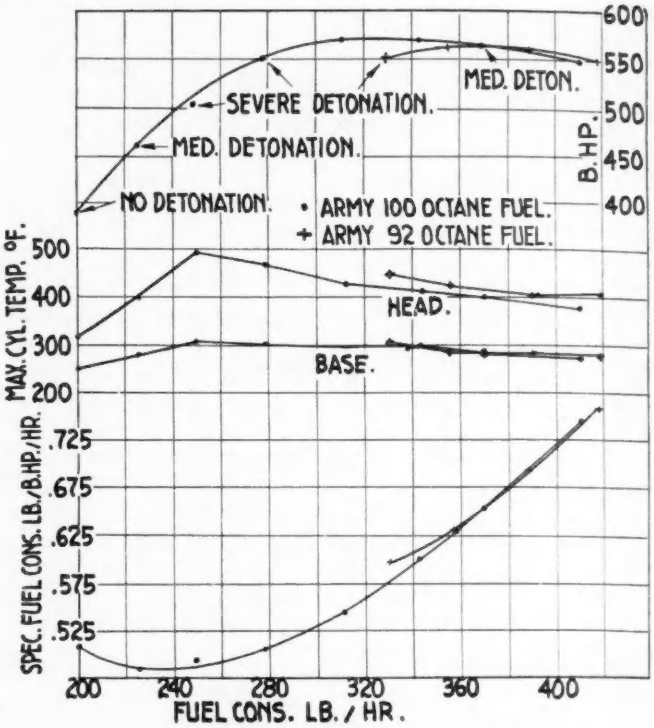

Fig. 2—Constant-Throttle Mixture-Control Runs—100-Octane Vs. 92-Octane Fuel—10:1 Blower-Gear Ratio
Cyclone engine; 6.45:1 compression ratio; 11-in. impeller diameter; 1837 r.p.m.

diameter impeller, to cover a range of operating conditions from cruising to take-off power. Regular Army 92-octane and regular Army 100-octane fuels were to be compared in a limited number of tests and, because of the marked value of Power Plant Fuel No. 552, a toluene blend, in the single-cylinder engine tests illustrated in Fig. 1, it was decided to include this fuel. The original batch having become exhausted, an additional quantity was furnished; it was designated as Power Plant Fuel No. 560. As compared with an Army octane number of 97 for Fuel No. 552, Fuel No. 560 was found to be better than 100 octane, being equal to certified iso-octane plus 0.3 cc. $PbEt_4$ per gal. This difference is due entirely to the use of different batches of blending material in the finished fuel since the percentage composition is the same for each fuel.

The engine used is rated at 850 hp. at 2100 r.p.m. Six series of variable-throttle, mixture-control runs were scheduled, varying from 570 hp. at 1837 r.p.m. for normal cruising to 930 hp. at 2200 r.p.m. for take-off. In each run and for each fuel the throttle was adjusted to give the desired horsepower at the desired speed with the mixture control set for best power. The throttle was then locked, and readings were taken over a range of fuel consumptions by varying the mix-

Table 3

Series No.	Figure No.	Carburetor-Air Temperature, deg. fahr.	Fuel-Air Mixture Temperature, deg. fahr.	Fuel-Air Ratio
1	2	76	162-183	0.040-0.104
2	3	73	160-184	0.062-0.106
3	4	75	105-130	0.052-0.102

[4] See *Journal of the Aeronautical Sciences*, May, 1935, pp. 125-126; Letter to Editor, by Val Cronstedt, R. N. DuBois, F. D. Klein, and S. D. Heron.

ture control. Air blast was reduced to make detonation more evident by increasing the cylinder temperature.

It was hoped that all of the tests would be completed in sufficient time to permit of reporting herein, which would have shown an interesting comparison of the value of the toluene blend at high output in this engine with its performance in the single-cylinder engine. However, due to unforeseen difficulties, only three series have been completed to date, all at 1837 r.p.m., as follows:

Comparison	Desired Maximum B.Hp.	Blower-Gear Ratio
(1) Army 92 octane vs. Army 100 octane	570	10:1
(2) 100-octane toluene vs. iso-octane blends	637	10:1
(3) 100-octane toluene vs. iso-octane blends	637	7.14:1

The first series represents normal cruising at 87½ per cent of rated speed, on the propeller load curve, which cruising requires 67 per cent of rated power. The second and third series represent, at two different blower-gear ratios, the maximum allowable continuous cruising condition at 87½ per cent of rated speed, with the use of 75 per cent of rated power which would be obtainable by the use of a controllable-pitch propeller.

The carburetor-air temperature, fuel-air mixture temperature, and fuel-air ratio for each of the three series are shown in Table 3. The fuel-air ratio followed approximately a straight line, the lowest value shown in the table corresponding with the lowest fuel consumption, and the fuel-air ratio points for both Army 92-octane and 100-octane fuels fell on the same line.

Fig. 2 shows the results of the first series of tests. Brake horsepower, maximum cylinder-head and base temperatures, and specific fuel consumption are plotted against fuel consumption. The maximum allowable cylinder-head and base temperatures for this engine are 500 deg. fahr. and 325 deg. fahr., respectively. At the point corresponding to the maximum head temperature shown for Army 100-octane fuel, with severe detonation indicated, the engine would have overheated if allowed to operate continuously, so flash readings were taken. On further leaning out to the point of maximum economy, cylinder temperatures and detonation were reduced. At the point corresponding to the minimum specific fuel consumption shown for Army 92-octane fuel, detonation would not permit of leaner operation, so that maximum economy could not be reached.

It is to be noted that the slight difference in maximum brake horsepower shown for the two fuels in Figs. 3 and 4, as well as in Fig. 2, has no significance whatsoever; the throttle in the case of each fuel was set as closely as possible to give the maximum desired power which was arbitrarily selected for the series of tests, so that the variation in maximum power was due entirely to difficulties in obtaining closer adjustment of the throttle. The most significant data of Fig. 2 are shown in Table 4.

Table 4

Blower-Gear Ratio, 10:1 — Desired Maximum B.hp., 570

Fuel	Setting	B.hp.	Specific Fuel Consumption, lb. per b.hp-hr.	Fuel Consumption, lb. per hr.
Army 92	Best Power	565	0.655	369
Army 100	Best Power	570	0.547	312
Army 100	Maximum Economy	462	0.485	225

From these data it is seen that, at a power output equivalent to normal cruising with mixture control set for best power, 19.7 per cent higher fuel consumption will be required with Army 92-octane fuel over that possible with Army 100-octane fuel.

Fig. 3 shows the results of the second series of tests, in form similar to that used in Fig. 2. At the point corresponding to the minimum specific fuel consumption shown for the iso-octane blend of Army 100-octane fuel, leaner operation was prohibited by overheating due to detonation, so that maximum economy could not be reached. The most significant data of Fig. 3 are shown in Table 5.

Table 5

Blower-Gear Ratio, 10:1 — Desired Maximum, B.hp., 637

Fuel	Setting	B.hp.	Specific Fuel Consumption, lb. per b.hp-hr.	Fuel Consumption, lb. per hr.
Iso-octane Blend	Best Power	640	0.605	388
Toluene Blend	Best Power	630	0.615	386
Toluene Blend	Maximum Economy	540	0.517	278

From these data it is seen that, at a power output equivalent to maximum allowable continuous cruising with a controllable-pitch propeller and a 10:1 blower-gear ratio with the mixture control set for best power, 1.6 per cent higher fuel consumption will be required with the toluene blend over that possible with the iso-octane blend, but that the toluene blend

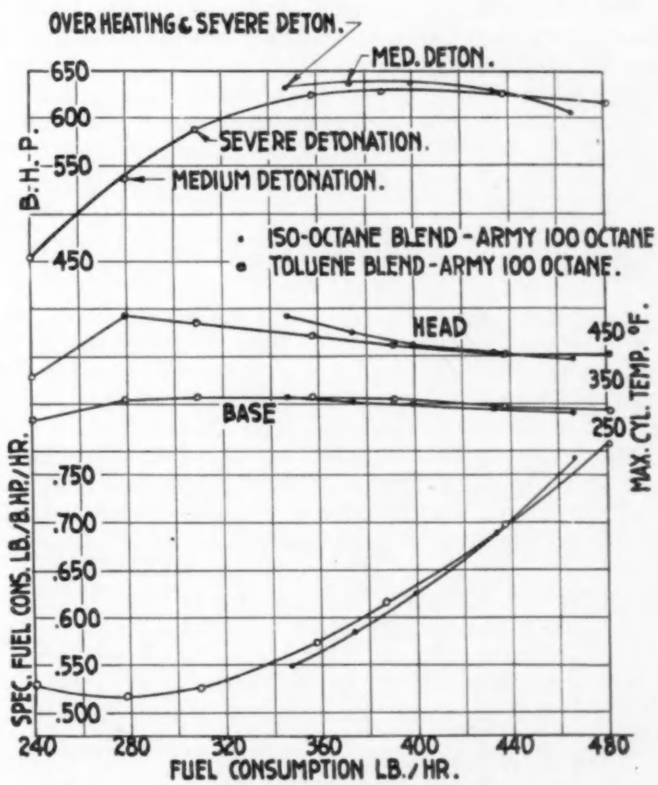

Fig. 3—Constant-Throttle Mixture-Control Runs—100-Octane Fuels—10:1 Blower-Gear Ratio

Cyclone engine; 6.45:1 compression ratio; 11-in. impeller diameter; 1837 r.p.m.

can be leaned out to give considerably lower specific fuel consumption than the iso-octane blend, with a corresponding reduction in brake horsepower.

Fig. 4 shows the results of the third series of tests, similar to the second series except for lower blower-gear ratio. In this case no detonation occurred with either fuel. The most significant data are shown in Table 6.

Table 6

Blower-Gear Ratio, 7.14:1 — Desired Maximum B.hp., 637

Fuel	Setting	B.hp.	Specific Fuel Consumption, lb. per b.hp-hr.	Fuel Consumption, lb. per hr.
Iso-Octane Blend	**Best Power**	637	0.520	330
Toluene Blend	**Best Power**	627	0.555	352
Iso-Octane Blend	**Maximum Economy**	575	0.443	253
Toluene Blend	**Maximum Economy**	567	0.463	252

From these data it is seen that, at a power output equivalent to maximum allowable continuous cruising with a controllable-pitch propeller and a 7.14:1 blower-gear ratio with the mixture control set for best power, 6.7 per cent higher fuel consumption will be required with the toluene blend over that possible with the iso-octane blend and that, with each fuel leaned out to maximum economy, 4.5 per cent higher fuel consumption will be required with the toluene blend over that possible with the iso-octane blend, the corresponding reduction in brake horsepower being appreciably the same with each fuel.

From a comparison of the data in Tables 5 and 6 at best power for both the iso-octane and the toluene blends at the two blower-gear ratios shown, it is seen that 11-16 per cent higher specific fuel consumption is required at the higher than at the lower ratio, for the same brake horsepower. This result is due to the fact that, since more power is required to drive the supercharger at high gear ratio, the indicated horsepower is greater for the higher gear ratio at equal brake horsepower; higher manifold pressure is required to give the same brake horsepower; and the fuel-air mixture temperature is likewise higher with the 10:1 gear ratio.

An accurate interpretation of the relative values of the iso-octane and toluene blends can be made only after the completion of tests at higher output, since a fuel to be satisfactory for all service purposes must allow both high output for take-off and climb and low consumption for cruising.

The maximum fuel economy possible with Army 100-octane fuel in engines designed specifically for operation on such fuel, is not shown by these tests because of the standard compression ratio used. As previously reported, the Wright Aeronautical Corp. has already obtained specific fuel consumptions as low as 0.34 lb. per b.hp-hr. in an engine similar to that used in the Air Corps tests except for high-compression-ratio pistons (7.85:1). The Air Corps plans, in the immediate future, to conduct 300-hr. endurance tests of both an R-1820 (Cyclone) and an R-1830 (two-row Pratt & Whitney Wasp) engine, with a compression ratio of about 8:1 and under conditions simulating maximum output for take-off; somewhat reduced output for climb; and long-time operation at cruising power at the lowest specific fuel consumption obtainable.

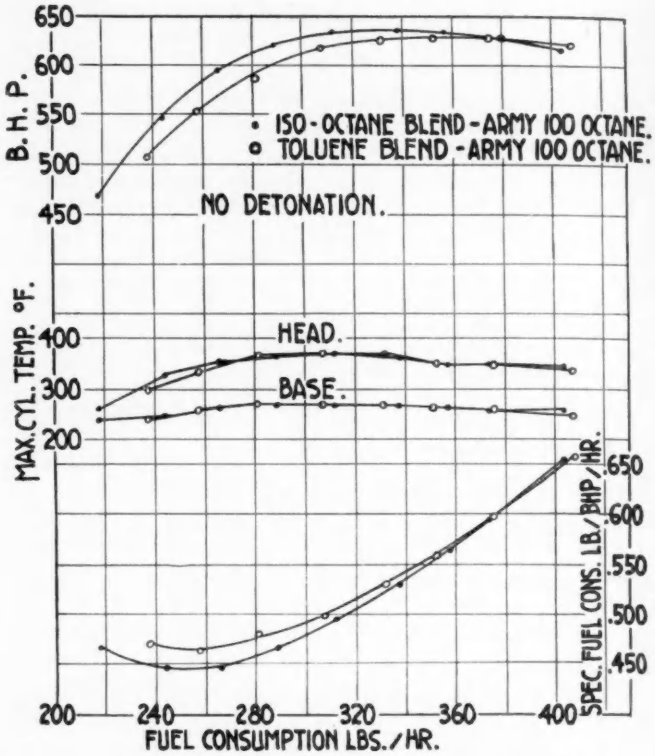

Fig. 4—Constant-Throttle Mixture-Control Runs—100-Octane Fuels—7.14:1 Blower-Gear Ratio

Cyclone engine; 6.45:1 compression ratio; 11-in. impeller diameter; 1837 r.p.m.

Available Supply

There is considerable difference of opinion regarding the total potential supply of 100-octane fuel available in this country from the blending of approximately equal quantities of iso-octane and regular aviation gasoline. This difference is to be expected since iso-octane is at present produced in commercial quantities only by a limited number of the leading refineries, and much remains to be learned regarding its most economical production. Egloff[5] states that "The gaseous hydrocarbons available in the United States are a potential supply of over 1,000,000,000 gal. of iso-octane gasoline a year, or more than 15 times the total consumption of aircraft fuel in the United States in 1934." Cooke, Swanson, and Wagner[6] estimate that there can be produced over 1,200,000,000 gal. per year of 100-octane fuel containing 80 to 85 per cent of aromatics. It suffices from the military standpoint to state that, from estimates submitted, the Air Corps is convinced that sufficient 100-octane fuel will be available as required.

Neptune and Trimble[7] have shown that an increase in the allowable Reid vapor pressure of aviation fuel to 9 lb. per sq. in. will make available 131 per cent of the 100-octane fuel that is now obtainable with 7 lb. per sq. in. vapor pressure from a given quantity of iso-octane, due to the permissible use of a higher percentage of iso-pentane which is available in large quantity at relatively low cost. Higher increases in the allowable vapor pressure will have a still more marked effect on the available supply of 100-octane fuel; for example, an increase to 12 lb. per sq. in. Reid vapor pressure will make

[5] See *National Petroleum News*, Nov. 20, 1935, pp. 25-32; "A Tool of Great Economic Utility", by Gustav Egloff.

[6] See *National Petroleum News*, Nov. 20, 1935, pp. 33-44; "Variations in Operating Conditions Change Properties of Polymerized Fuel", by M. B. Cooke, H. R. Swanson, and C. R. Wagner.

[7] See paper presented before Southeastern Kansas Section Meeting of American Chemical Society, Nov. 16, 1935; "The Role of Iso-Pentane in the Manufacture of 100-Octane Aviation Gasoline".

available 238 per cent of the 100-octane fuel obtainable under the present specification. Largely in view of these data, the Air Corps will investigate the feasibility of operating military aircraft with fuel of 9 lb. per sq. in. vapor pressure during the coming summer.

The use of fuels of high aromatic content, containing no iso-octane, such as the toluene blends reported herein, might be of decided value in the future, particularly since new methods for the economical production of aromatics are now available which make it appear certain that considerably more of these fuels can be produced than were available 15 years ago. In addition, other processes are being developed for the production of high antiknock fuel which will not only increase the available supply and reduce the cost of 100-octane fuel, but which will make available large quantities of much better fuels.

Military Procurement

The Air Corps has purchased approximately 1,850,000 gal. of 100-octane fuel for use during the fiscal year beginning July 1, 1935. This fuel is in general service use at Hamilton and March Fields, Calif.; Selfridge Field, Mich.; and Barksdale Field, La. A small portion is being used for experimental purposes at Wright Field, O. This fuel all conforms with Specification No. 2-92, which provides for no changes whatsoever in properties over regular Army 92-octane fuel except for the higher antiknock value and a reduction in the maximum allowable tetraethyl-lead content from 6 to 3 cc. per gal. to reduce engine-corrosion difficulties. In addition, Specification No. 2-90 has been issued covering unleaded Army 92-octane fuel, intended for the routine block-testing of engines at depots as a means of reducing engine corrosion during storage. For the fiscal year beginning July 1, 1936, the Air Corps contemplates the procurement of 2,841,000 gal. of 100-octane fuel and 700,000 gal. of unleaded Army 92-octane fuel.

The Bureau of Aeronautics, Navy Department, on February 1, 1936, issued Specification M-302, covering high-octane aviation gasoline which, with not more than ½ cc. of tetraethyl lead per gal., is required to have an antiknock value of 87 octane by the A.S.T.M. method. With additional lead added to bring the total content to not over 3 cc. per gal., the fuel is required to be not poorer than 100 octane by the Air Corps method of knock test and to conform with all requirements of Army Specification 2-92 covering 100-octane fuel.

The purpose of this Navy specification is to provide fuel conforming with past Bureau of Aeronautics requirements for 87-octane fuel, but which contains a very small concentration of tetraethyl lead in order to reduce engine corrosion; and which, because it consists of the same base as is used in the 100-octane fuel being furnished to the Air Corps, will assist the fuel industry in the development of facilities for producing high antiknock fuels and thus make it possible to procure 100-octane fuel easily when desired for the improvement of engine performance.

Commercial Possibilities

Knowing the relative specific fuel consumptions possible with both commercial 87-octane and 100-octane fuels, computations to show a saving in payload with 100-octane fuel are simple. Young[2] has quoted a possible hourly saving of 50 lb. of fuel per engine for transports. E. L. Bass[8] has plotted representative curves demonstrating how great a range of flight is required to justify, in increased payload, the payment of increased price for higher antiknock fuels although, at the time of publishing his paper, the low consumption possible with 100-octane fuel was not known.

It is believed that the two following comparisons, one based on normal operation of airlines in this country and the other on trans-oceanic operation, are very conservative illustrations. The computations are based on 850-hp. engines cruising at 67 per cent of rated power with two engines in the continental limits of the United States, and 60 per cent of rated power with four engines in trans-oceanic service to further reduce the fuel consumption. A specific fuel consumption of 0.44 lb. per b.hp-hr. is assumed for commercial 87-octane fuel, and 0.38 lb. per b.hp-hr. for 100-octane fuel. The cost of commercial 87-octane fuel is figured as 14 cents per gal., and the cost of 100-octane fuel as 16 cents per gal., present indications being that approximately this differential will exist after 100-octane fuel has come into general use.

Illustration 1
(Continental Limits)

	Commercial 87-Octane Fuel	100-Octane Fuel
Lb. fuel per hr.	502	434
Gal. fuel per hr.	84	72
Cost of fuel per hr.	$11.75	$11.53
Saving, lb. of fuel per hr.	....	68

Illustration 2
(Trans-Oceanic Service)

	Commercial 87-Octane Fuel	100-Octane Fuel
Lb. fuel per hr.	898	775
Gal. fuel per hr.	150	129
Cost of fuel per hr.	$20.98	$20.68
Saving, lb. of fuel per hr.	....	123

It is seen that, while the cost of 100-octane fuel per gallon is higher than that of commercial 87-octane fuel, the reduction in consumption results in a slight saving in total fuel cost. The increase in payload, however, obviously would justify somewhat higher fuel cost. In the case of a flight from California to Hawaii, a distance of 2410 miles, a cruising ground speed of 140 m.p.h. would require a flight duration of 17 hr., 12 min., resulting in a possible increase of 2118 lb. in payload. Greater range or higher cruising speed rather than increased payload can, of course, be obtained when preferred. With engines operating with high compression ratio on 100-octane fuel, and at outputs no higher than now used for similar engines of normal compression ratio using commercial 87-octane fuel, overheating of engines at extremely low specific fuel consumption should not be expected since specific-heat rejection is lower with the higher compression ratio. Engine corrosion will not increase since the tetraethyl-lead content is no higher than in the past, being in fact lower for military engines than in fuels previously furnished.

To take the maximum advantage of 100-octane fuel, engines must be designed specifically for its use. There are two extremes of conditions for which engines can be designed. On the one hand are long-range airplanes, in which low specific fuel consumption is of major importance. In this case, increases in engine weight per horsepower to give the added mechanical strength required incidental to the greater peak pressures present with high compression ratio are not of

[8] See *Journal of Royal Aeronautical Society*, October, 1935, pp. 879-962; "Fuels for Aircraft Engines", by E. L. Bass.

serious disadvantage. On the other extreme are short-range airplanes for which maximum speed and rate of climb are of major importance, with specific fuel consumption being secondary. In this case a high degree of supercharge without excessively high compression ratio will be used, and a decided reduction in engine weight per horsepower will be possible. For intermediate-range airplanes, any desired compromise between these extremes is possible to provide the power required for take-off and to maintain reasonable speed during climb, with fuel consumption reasonably low during cruising.

The advantages of 100-octane fuel are so marked that there is little doubt but that it will be adopted for general airline use in the not too distant future. However, for the benefit of operators who today are most interested in reduction of engine corrosion, the use of commercial 87-octane fuel containing not more than ½ cc. of tetraethyl lead per gal. deserves consideration. This fuel has been made possible by the 100-octane fuel-development program, and it probably will cost about 1 cent per gal. less than 100-octane fuel. This small concentration of lead causes almost negligible corrosion but, if commercial 87-octane fuel without any lead is desired, it will be available at a cost of probably about 1 cent per gal. above 100-octane fuel.

Future Development

There is every reason to believe that the quality of fuel will continue to improve in the future just as it has in the past. 100-octane fuel is merely a stepping stone. As better fuels become available, engines will be designed to take advantage of them. And, conversely, as newly designed engines are found to give improved performance with higher antiknock fuels, methods of producing the better fuels will be developed.

Most of the past experience with 100-octane fuel has been obtained with iso-octane blends. The fuel industry is making rapid progress in developing new methods for producing iso-octane at lower cost and with large potential source of supply. Methods have just been developed which give indication of making available large quantities of fuel better than 100 octane without lead, and considerably better with added lead, at moderate cost. Much of course still remains to be accomplished along these lines since the development of fuels better than commercial 87 octane is only a little over two years old.

Improvements in the antiknock value of fuels and development of engines that can take advantage of the improved fuels necessitate the conductance of full-scale engine tests as a means of obtaining correlation data with different types of fuels, for use in arriving at a satisfactory knock-test method which will rate fuels in the relative order of their actual performance in the average of engines in service use. The results of recent cooperative full-scale engine tests of fuels, covering a range of antiknock values up to about 90 octane, have been reported by C. B. Veal[9].

Knowing the relative behavior of different types of fuel in full-scale engines, there remains considerable laboratory investigation to determine what knock-test method is the most satisfactory. Then, since the present scale of antiknock value goes only as high as 100 octane and since considerably better fuel than this is already available, it is obvious that a new scale must be developed with high enough range to include the best fuels believed likely to become available within a reasonable length of time. This development might be accomplished by the use of a primary reference fuel considerably superior to the iso-octane that is now used, or it might be accomplished by a radical departure from present knock-test procedure as suggested by Boerlage, Peletier and Tops[10].

The vast amount of work involved in these factors of engine performance of fuels, methods of knock test, and scales of antiknock value, requires so much time and expense that reasonable progress has been possible only through the cooperative efforts of the interested parties. The Aviation Gasoline Detonation Subcommittee of the Cooperative Fuel Research Committee has succeeded so well in the past in coordinating the progressive efforts of the fuel and aircraft-engine industries, the Army and Navy, and the Bureau of Standards; and so much still remains for the future that it is essential for continued support to be lent to this Subcommittee in the interests of better fuels, improved engine performance, and universally accepted methods of knock testing.

Acknowledgments

The author desires to acknowledge the work of Ford L. Prescott who conducted the high-output single-cylinder engine tests reported herein; of R. V. Kerley who conducted the multicylinder engine tests at the Materiel Division; and to give credit to the other engineers of the Power Plant Branch who have kindly assisted by offering helpful suggestions.

[9] See S.A.E. TRANSACTIONS, May, 1936, pp. 161-175; "Rating Aviation Fuels in Full-Scale Aircraft Engines", by C. B. Veal.

[10] See *Aircraft Engineering*, December, 1935; "The Allowable Boost Ratio", by G. D. Boerlage, L. A. Peletier, and J. L. Tops.

Discussion

Branched-Chain Ethers Discussed

—S. D. Heron
Ethyl Gasoline Corp.

LIEUTENANT KLEIN has emphasized the case for higher octane number fuels and shown that they have produced increases of engine performance which would necessitate an extremely expensive and lengthy engine-development program to obtain a similar result with the present standard 87-octane (Motor method) fuel.

The wide divergence between the relative ratings of iso-octane blends and aromatic blends on the liquid-cooled single-cylinder engine and the air-cooled multicylinder engine indicates some of the difficulty of the problem of devising a method of rating fuels for aircraft engine use. The single-cylinder engine shows results similar to those reported by Mr. Wood[a]. Such widely variable ratings are likely to produce a state of some confusion in those working on methods for laboratory rating of aircraft-engine fuels. The development of an international standard for rating aircraft-engine fuels will not be facilitated by the fact that the balanced diet of a British liquid-cooled engine appears to be sensibly different from that of an American air-cooled engine.

With reference to the data given by Mr. Wood on 77-octane number fuels of high- and low-aromatic content, it would appear that the fuel of low-aromatic content must have contained an antiknock blending agent since straight-run aircraft-engine fuels of low-aromatic content and 77-octane number are not normally commercially available unless the Air Ministry vapor-pressure specifications are exceeded.

I think that the branched-chain ethers discussed by Messrs. Aldrin and Buc[b] represent the outstanding discovery in the antiknock field since the discovery of paraffins of high antiknock value. This opinion is based on study of both knock-test and full-scale aircraft-engine data.

Our laboratory has found the blending octane number of di-ethyl ether to be minus 25 as determined by the Army method on a blend of 25 per cent di-ethyl ether in 75 per cent technical iso-octane. This

[a] See S.A.E. TRANSACTIONS, July, 1936, pp. 267-287; "Liquid-Cooled Aero Engines", by H. Wood.

[b] "A New High-Octane Blending Agent", by H. E. Buc and Maj. E. E. Aldrin, presented at the Semi-Annual Meeting of the Society, White Sulphur Springs, West Va., June 5, 1936.

result may be open to doubt since the ether used was not tested for peroxides. The low-octane number of di-ethyl ether suggests the use of high-molecular-weight, straight-chain ethers for specially low-octane number or high-octane number reference fuels.

Our laboratory has found the octane number of di-isopropyl ether to be 98½ and that of tertiary butyl-ethyl ether to be 100 plus 0.1 cc. of lead, both figures being determined by the Army method. Tertiary butyl-isopropyl ether would appear to have possibilities as a high-octane reference fuel, and our laboratory will shortly carry out some tests on it.

Importance of Volatility Stressed

—H. M. Trimble
Phillips Petroleum Co.

LIEUTENANT KLEIN has not only discussed the engine side of the story but also the fuel side. However, it is felt that it might not be amiss to emphasize further certain points regarding fuels.

Let us take a look at a chart, published some time ago for Lovell, Campbell and Boyd[a] and reproduced in Fig. *A*. It does not take much study of this chart before one realizes that the production of iso-octane (2, 2, 4-trimethylpentane) in making 100-octane gasoline really just scratches the surface. The other compounds with antiknock values approximating 100-octane number should be studied because they undoubtedly will become competitors of iso-octane. As a result the properties of these compounds and the raw materials required for their production are of definite interest.

It is noted that most of these possible fuels have greater volatility than iso-octane. These volatilities take on a real significance when one thinks of the low vapor pressures and volatilities now imposed on aviation gasoline. As an example of these fuels take 2, 2-dimethylbutane, a hydrocarbon with 95 A.S.T.M. octane number requiring about 0.5 cc. tetraethyl lead per gal. to make 100-octane number but with a boiling point and Reid vapor pressure of approximately 123 deg. fahr. and 9.5 lb. per sq. in. respectively. The sum of the 10 and 50 per cent evaporated temperatures of this fuel would seriously violate present specifications. It should be emphasized further that, even if a compound had a Reid vapor pressure of 7 lb. per sq. in., the sum of the 10 and 50 per cent evaporated temperatures would only be approximately 280 deg. fahr.

[a] See *Industrial and Engineering Chemistry*, January, 1931, pp. 26-29; "Detonation Characteristics of Some Paraffin Hydrocarbons", by Wheeler G. Lovell, John M. Campbell, and T. A. Boyd.

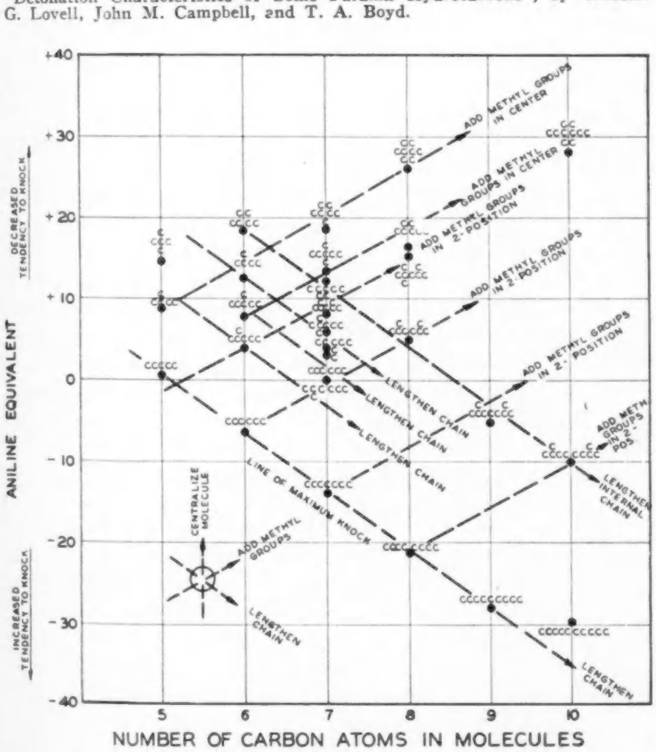

Fig. *A*—(Trimble Discussion) Relationship of Molecular Structure to Detonation Characteristics for Paraffin Hydrocarbons

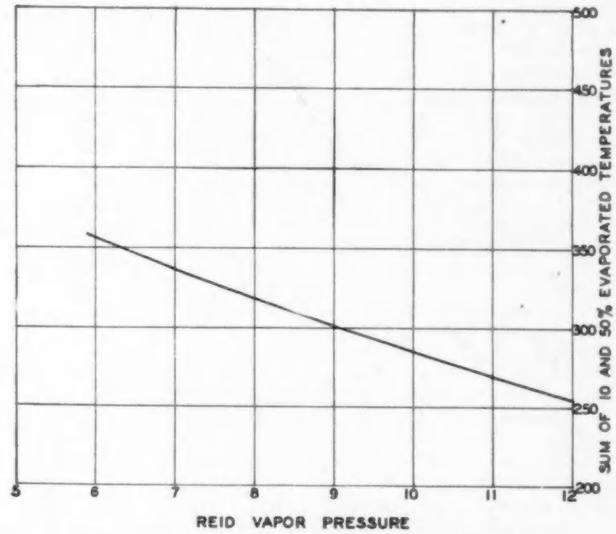

Fig. *B*—(Trimble Discussion) Effect of Reid Vapor Pressure on Sum of 10 and 50 Per Cent Evaporated Temperatures

Now let us compare the raw materials. Iso-octane requires the use of butane, a marginal product in the manufacture of motor fuels, whereas the hexane just mentioned requires the use of what is essentially a waste product of the oil industry. This is a real consideration in the cost of the final product.

As another point of importance, let us analyze further the subject of higher vapor pressures. Lieutenant Klein already has pointed out the possibilities of increased supplies of high-octane materials by increasing the maximum Reid vapor pressure, but let us take a look at the effect of this increase on the sum of the 10 and 50 per cent evaporated temperatures. In Fig. *B* this effect is shown. The 7 lb. per sq. in. vapor pressure aviation gasoline shown is well above the present limitations but, when its vapor pressure is increased to 9 lb. per sq. in., the present specifications are violated. In the case shown the change in the sum of the 10 and 50 per cent evaporated temperatures is 35 deg. fahr. for the change in Reid vapor pressure from 7 to 9 lb. per sq. in.

In summary, it becomes quite evident that, just because we now have iso-octane for making 100-octane fuel, our work on fuel-induction systems is not at an end. Volatility still is a very important factor especially when considering the cheapness and availability of fuels. The aviation industry, therefore, should still be vitally interested in volatility.

As a suggestion, why not build these new planes with engines requiring 100-octane fuel with induction systems that can handle the vapor pressure and volatility situation also?

Price Trend Analyzed Further

—J. H. Doolittle
Shell Petroleum Corp.

WHEN the Army concludes the experiments suggested by Lieutenant Klein in which high-output engine tests will be made with various intake temperatures, it will be interesting to see whether or not aromatics depreciate with increasing intake temperature. It also will be interesting to check individual aromatics and to ascertain whether or not there is any increase in temperature stability with complexity of structure. For instance, is benzine less temperature-stable than toluene, and is xylene more temperature-stable? There seems to be some indication that this is the case.

In regard to the price of 100-octane fuel, I would like to bring out the following points:

Just about a year ago the first 100,000 gal. delivery of 100-octane fuel was made to the U. S. Army Air Corps at Hamilton Field, Calif. The successful bidder, and there was only one company in the United States able to bid on the material at that time (Shell Chemical Co.), received 50 cents per gal. for this material. It was made in a pilot plant on a semi-production part-laboratory scale. From January, 1936, to date the Army has used about a million gallons of 100-octane fuel. It purchased this quantity for about 25 cents per gal.

On June 4, bids were opened for the Army's requirements from July 1, 1936, to Jan. 1, 1937. The amount called for was about two million gallons. The successful bidders obtained the business at 18 and 20 cents per gal. I might say at this point that between these two dates the Navy purchased 330,000 gal. of Army 100-octane base stock with 0.3 cc. of lead instead of 3 cc. of lead, for which they paid 22½ cents per gal. The tendency is obvious. The cost of 100-octane fuel will continue to decrease as production and consumption increase and as more competitors come into the field. The effects of additional competition will be improved and more economical manufacturing methods and probably the discovery and production of new blending materials. I am satisfied that the price curve will eventually approach parallelism with the curve for 92-octane fuel, or rather straight-run aviation-base stock, but I do not feel that it will ever become asymptotic to it.

I further feel that the 2-cent premium suggested by Lieutenant Klein is a bit optimistic. The reasons for this belief are as follows:

First, high-octane fuel will always be a premium product. There is the expense and difficulty of taking out of the whole a premium part and leaving the rest of less value (like taking the middle eighteen inches out of a yardstick and throwing away or finding some less valuable use for the two nine-inch ends).

Second, there is the fact that straight-run aviation gasoline is made in the same refinery and with the same equipment as motor gasoline, although premium-grade crudes are, of course, required. Aviation gasoline is probably less than one per cent of the total; still, being made in the same equipment, it enjoys the reduction in cost resulting from large production. One hundred-octane fuel, made of special blending components, will have to be made in special equipment and, consequently, will not enjoy the price reduction resulting from large motor-gasoline production.

There will be a decided reduction in price when the Army and Navy go to 100-octane fuel exclusively.

It is probable that a reduction in manufacturing costs and, consequently, a reduction in price might be obtained were there a greater latitude in aviation-gasoline specifications. The present specifications call for a very volatile fuel in order to assure proper distribution. Recent improvements in induction systems – improved distribution resulting from rotary induction, heat, turbulence, and so on – may permit the use of higher-boiling-point components. It would be interesting to have the engine manufacturers' reactions on this point. Iso-dodecane, which is now practically a waste product in connection with the manufacture of iso-octane due to its high boiling point, has substantially the same knock-rating as iso-octane. If it could be included without interfering with distribution or causing crankcase dilution, it would have the dual advantage of reducing cost and increasing the mileage per gallon which, considering tankage, is equivalent in a degree to reduced specific fuel consumption.

There is no question but that 100-octane fuel is merely a stepping stone to the higher knock-rating fuels of the future. Still, we have to stabilize some place in order that engines and fuel may catch up with each other, and it is felt that 100-octane fuel is a satisfactory optimum for the next five years.

The extremely low specific fuel consumption obtained with aromatic fuels is of academic rather than optional interest because it is very unlikely that a pilot would go from a condition of satisfactory operation through a period of serious detonation in order to get another period of lower power output and improved fuel economy.

Author Explains Divergencies in Closure

—Lieut. F. D. Klein
U.S. Army Air Corps

REGARDING the wide divergence between the relative ratings of iso-octane blends and aromatic blends in air-cooled and liquid-cooled engines, one point worthy of mention is that cylinder temperature was used as the criterion of limiting output in the case of air-cooled engines; whereas audible detonation was the criterion in the case of the high-output single-cylinder liquid-cooled engine. Since aromatics are known to possess overheating tendencies under some conditions without the presence of audible knock, entirely different ratings of the aromatic blends might have been obtained in the liquid-cooled engine if some criterion of limiting output possibly of more significance than audible knock had been used.

With reference to the volatility limitations now placed on high antiknock fuels by Army specifications, there is no reason to consider that such requirements must always remain as they are at present. Revisions of fuel specifications will be made by the Air Corps whenever considered justified on the basis of the fuel itself, provided of course that unsatisfactory engine performance, operation, or weight will not be occasioned thereby. The volatility limitations will always be a compromise between what is most desirable from the standpoint of both cost and availability of the fuel, and performance and weight of the engine.

Slow Motion Shows Knocking and Non-Knocking Explosions

(Continued from page 303)

fronts may be followed by observing the many luminous spots which appear on the pictures of the inflamed gases. When at rest, these spots appear to be approximately spherical but, when their motion is appreciable during the 1/2500 sec. in which the picture is being exposed, the spots lengthen out into streaks, the lengths of which are determined by the distances moved during the exposure.

Now, in general, it will be observed that these spots moved back from the flame front indicating, as pointed out in the description of Fig. 3, that the gasoline burned in the flame front. In pictures Nos. 12 and 13 of explosion *A*, for example, distinct backward motion is evident behind the flame front not only in the region over the piston but likewise in that over the exhaust valve.

But the important feature in Fig. 6 is the tremendous increase in velocity of these luminous spots at the time of knock. This phenomenon, while evident in every explosion, is particularly striking in pictures Nos. *A*-14, *B*-15, and *E*-14. The gas motion is, of course, induced by the sudden burning and expansion of the portion of the charge that burns last.

The direction of the gas movements caused by knock varies with the position in the combustion space where auto-ignition occurs. This effect is illustrated particularly well by pictures Nos. 14 exposed from top dead-center until 2.2 deg. past top dead-center in explosions *A, C, E,* and *F*. For example, in explosion *A* the gases move directly toward the spark-plug and valves, while in explosion *C* the gases are reflected by the wall of the combustion-chamber shown at the lower side of the picture. Similar directional gas movements can be observed in other knocking explosions.

The violent gas movements evident in Figs. 5 and 6 just after knock occurs appear to be closely related to the three undesirable consequences of knock: the sound; the increased jacket temperature, particularly in air-cooled engines; and the loss of power. The relationship between the gas movements and the sound of knock already has been discussed in some detail[11]. The increased jacket temperature and loss of power both undoubtedly result from increased heat transfer from the gases to the walls. It is apparent that this heat transfer would be greatly augmented by the "scrubbing action" of the high gas velocities induced by knock.

Acknowledgments

Acknowledgments are due the several members of the General Motors Research staff who have either directly or indirectly participated in the construction and development of the apparatus used for recording the flame pictures.

Special mention should be made of the valuable assistance rendered by H. H. Love in the design of the cylinder-block; by C. J. Kinsey in the design of the combustion camera, and by Dr. V. C. Smith in the development of a printer to be used in preparing projectible positives.

[11] See *The Automobile Engineer*, August, 1934, pp. 281-284; "Engine Knock", by Lloyd Withrow and Gerald M. Rassweiler.

Safety in Motor-Vehicle Operation and Maintenance*

By J. M. Orr
General Manager, Equitable Auto Co.

PROGRESS that has been made in the study of industrial accidents, covering factors that are involved in accident prevention in the operation of small cars and trucks and auxiliary equipment, is discussed in this paper.

This paper also deals with the driver viewpoint, giving statistical data and methods for determining responsibility, driver qualifications, and the like.

The problem also is approached from the viewpoint of safety as affected by vehicle design, operation (without respect to the driver), and maintenance.

In collaboration with Mr. Orr, Mr. Newton discusses the problem from the points of view of traffic direction, educational campaigns, driving practices, and highway conditions. He touches on the right types of advertising propaganda and vehicle-design factors; he also gives interesting statistical data resulting from vehicular inspections in various states.

THE great masses of the American people are apathetic in their attitude toward motor-vehicle accidents. Their apathy is due primarily to the fact that individuals are not compelled to accept responsibility and furnish a proper final accounting for their careless acts. This condition has been so for many years, and it is so today. They seem to view the shocking toll of personal injuries and fatalities as something they can do nothing about. Individually, the position taken is that – "I am a safe driver; – the other motorists make it unsafe for me to travel the highways; – the irresponsible nitwits should be taken off the road." There is some justification for this attitude if we consider the average elapsed time between accidents.

In commercial operation, an accident for every 40,000 miles is not at all uncommon. Applied to other than commercial operations this rate would probably represent five years of driving and, even if it were only two years, that is a long time between accidents. During the interval, whatever it may be, the many miles that are driven without our being hurt or having our fenders bent lulls us into a state of overconfidence and laxity. We are off guard, and in an instant some kind of an accident occurs. It is usually minor, but every minor accident has major potentialties, and the line between them is a mighty fine one.

Our people are killed or injured in a minor part of the Nation's accidents. This situation gives rise to another phase of the problem that merits consideration. The fact that most accidents are minor in character and that it is the very occasional, or exceptional, accident in which fatalities or serious personal injuries occur, makes it difficult to educate vehicle operators to a realization of the grave possibilities that exist in every accident to the extent that they will actually drive safely at *all* times. Fatal accidents, as well as minor accidents, are due to the same faults. If we could have every driver know his faults, and not allow him to persist in them, accidents, both major and minor, would be few.

Most people drive safely most of the time because they are law-abiding by nature and are afraid to be hurt. They will, however, take occasional driving risks or chances, or they come upon a driving situation to which they cannot react capably and adequately. Their ability to discriminate between safe and unsafe driving practices in the wide variety of conditions encountered is not always the same. The exercise of judgment is adversely affected by many things from day to day. Accidents are born of occasional chances and split-second errors of judgment.

A reversal from the formerly tolerant sufferance of an increasing highway accident rate has occurred in the past two or three years. Our greatest and most influential public agencies and organizations, including the Society of Automotive Engineers, are devoting substantial portions of their facilities and attention to a nation-wide reduction of motor-vehicle accidents. Public opinion is being molded by extensive educational campaigns to reflect the advantages of accident-free motor-vehicle use. Many plans and campaigns are now getting under way, and we will see their good results as they are developed and applied further.

Our present position with respect to a reduction of motor-vehicle accidents is comparable with the position of industry some twenty or more years ago when it realized that its employees were being hurt too often at their jobs. It was decided then that accident frequency and severity were to be reduced to reasonable levels. As a result, substantial reductions have been effected and, with the unceasing efforts of management and efficient accident-prevention departments, substantial improvement continues to be shown from year to

*Prepared with the collaboration of L. V. Newton, automotive engineer, Byllesby Engineering and Management Corp.

[This paper was presented at the Semi-Annual Meeting of the Society, White Sulphur Springs, West Va., June 1, 1936.]

year. As an instance of accomplishment in this respect, I refer with pardonable pride to the June accident experience of the Duquesne Light Co., and to the June, 1935, experience of the Pennsylvania Electric Association.

Until 1925, the largest number of accidents to employees of the Duquesne Light Co. occurred in the month of June. In an effort to correct this situation, June, 1925, and June of each year since have been designated "No Accident Month". Every department of the company strives to show its best experience in June. The results show what has been accomplished by this annual effort, the good influence of which has extended to the other eleven months of the year.

June Lost-Time Accidents before 1925

1921	33	1923	28
1922	33	1924	19

June Lost-Time Accidents since 1925

1925	8	1931	None
1926	9	1932	2
1927	11	1933	1
1928	6	1934	1
1929	2	1935	None
1930	2		

Incidentally, it is interesting to note that, following the recent flood catastrophe in Pittsburgh in which almost irreparable damage was done the plant and facilities of the Duquesne Light Co., the herculean job of restoring service was accomplished without one serious accident to its employees.

June, 1935, was made No Accident Month by the electric utility companies comprising the Pennsylvania Electric Association. A campaign among the member companies was well planned and executed. Twenty-one companies had 8 lost-time accidents in June, 1935, compared with 23 similar accidents in 1934.

The results obtained by the Duquesne Light Co. and by the member companies of the Pennsylvania Electric Association were due entirely to the influence of management upon its employees. Briefly, it was control. If we had adequate law enforcement in the same degree, similar influence could be brought to bear upon the private driver with equally good results.

Commercial motor-vehicle accident experience can be similarly improved, and there is no reason to feel that our shocking public accident experience cannot be controlled and substantially bettered, once the forces of public opinion are turned against it.

General Aspects of the Problem

Fast Driving. – We often hear it said that fast driving is the particular cause of automobile accidents. Fast driving in itself is not a real cause of accidents. High speeds are only dangerous when engaged in under the wrong circumstances and when practiced by drivers who are incapable of seeing, thinking, or acting as fast as they drive.

There is a maximum safe speed to which every individual should limit himself. He should learn to recognize and respect that speed and be governed by its limitations on the highways.

In Europe, where most of the cars have low-horsepower engines for economy and license reasons and cannot be driven very fast, they have a higher accident rate than we have in this country.

A prominent insurance company tells us that, in a half million accidents that occurred in this country, 22 per cent were definitely due to cars being driven too fast. It might just as well have said that they were due to poor judgment on the part of vehicle operators.

Highways. – The highway must be considered in our study of safe vehicle operation. Large portions of our major highway systems are of narrow design, the same width as roads were in "horse and buggy" days. There are miles of obsolete major roads, too highly crowned, with bad curves, railroad grade crossings, poor surfaces, inadequate markings, and with very little of them lighted.

Motor-vehicle taxes collected from road users and intended for road construction and repairs should not be diverted to other purposes, as is now the fashion, but should be spent intelligently and economically on our highways.

Road Courtesy. – If everyone drove an automobile with as much care and courtesy as is exercised when walking down the street, accidents would be few and far between. It is peculiar but true that many people forget almost entirely or ignore the practice of courtesy toward other motorists and pedestrians while at the wheel of a motor vehicle. There seems to be a lack of the sense of personal responsibility for accidents, and of the terrible consequences that can follow them.

This indictment does not apply equally to all drivers. Most assuredly it is less applicable to commercial-vehicle operators, particularly those of fleets in which safe operation is not only stressed but controlled by the same means that management uses to develop efficiency in every other line of endeavor – that is, by training, supervision, and enforcement of operating rules and regulations.

Horror Advertising. – We do not believe in trying to frighten children into being good, neither do we believe that horror stories of automobile accidents with their gruesome illustrations do very much good. They are more apt to be definitely harmful.

The people that should be frightened are not intelligent enough to understand. Those who are sufficiently intelligent to understand, read such stories, are impressed and worry every time they drive their cars. The result is nervousness and attendant accident-proneness.

Educational Campaigns Must Be Understandable. – Dr. Will Durant tells us that only 1/60th of our population have a high school education. Here is what he says:

"We spend more money upon education than all the rest of the world put together, and yet there is no visible rise in the level of intelligence of the American people. I do not see any evidence that the American people by and large are more intelligent today on the average or in the total than they were 50 years ago.

"Why is there no appreciable rise in the level of our intelligence? Because the educational process, even at its best, reaches only a small fraction of us. There are only two million high-school graduates in the United States, one sixtieth of our population."

The foregoing is something that we lose sight of in planning safety campaigns. They must be designed for understanding at proper intelligence levels.

Education of school children on safety in walking along and crossing streets should have further urging. High schools should include courses of instruction in automobile driving in their curricula. A few of them are now giving this instruction.

Good Driving Is an Art. – Good driving is an art or an accomplishment, as is doing anything else well. Let us make

the art of good driving something to be proud of and something that all will strive to acquire. This job can be done through education in our schools, in our companies, and through editorial effort.

Commercial Accident Aspects

The vehicular accident records of most commercial operators are much better than average. This is due to their careful consideration of accident control in the same category and manner as that of any other of their ever-present operating problems.

Fleet operators accept accidents as an operating responsibility. Aside from the humanitarian aspects, a low accident record is looked upon as an index of good management and operating efficiency. Cost of claims, accident repair expense, loss of vehicle use, extraordinary vehicle depreciation, compensation or welfare to injured employees, interference with work programs and progress, unfavorable public reaction toward fleet-owning companies – these and other consequences emphasize the desirability of reducing fleet accidents.

The familiarity of fleet operators with accident facts and their experience with result-getting prevention measures should play a substantial part in the reduction of public accidents. It is hoped that this paper may serve in some measure as a means toward that end.

Factors Conducive to Safe Motor-Vehicle Operation. – The usual commercial fleet contains a wide variety of sizes, makes, and types of vehicles. Much of the work done with them, particularly trucks, exposes men and vehicles to accident hazards not normally prevalent.

Most commercial motor vehicles are incidentally-operated. Drivers are first engineers, salesmen, supervisors, service men, expert technicians, or craftsmen, employed for their primary abilities in these lines. The operation of motor vehicles is subordinate to their principal occupations. Our general objective should be to prohibit the operation of vehicles in company business by employees who do not possess satisfactory driving ability although, in exceptional instances, it seems that we must countenance vehicular operation by employees known to be mediocre drivers because of their exceptional value to the company in their principal occupations. This statement is not a confession of management weakness, but rather it is a truthful recognition of the fact that, in any sizable group of vehicle operators, there are bound to be some who hover close to the line between accident proneness and accident freedom. Every opportunity should be taken to minimize or eliminate exceptions of this nature.

A good fleet-accident experience is dependent upon several things. New vehicles must be chosen carefully. Vehicles must be maintained properly and adequately. Drivers must be capable and cooperative. They must realize their responsibilities to the public and to their employers. Above all, management must be sincere and definite in its desire for the safest possible operation.

Vehicle Selection

Small Cars and Trucks. – The power, performance, and road speed of available vehicles have been increased substantially in the past few years. Small cars and trucks used to travel at easy speeds and slow down on hills and grades. Vehicles of this type now make their trips at high speeds, zipping around and past larger cars and trucks with breathtaking ease and regularity.

Fleet operators feel that the performance and speed of currently available passenger cars and half-ton trucks are beyond the commercial need. Certainly the use of such speed and performance affects operating costs adversely. In the interests of safe and economical operation, top speeds are limited by the use of governors and similar devices. Some operators have expressed a desire for moderately performing small vehicles, built especially for commercial service. It would appear, however, that the outlook in this direction is rather limited, due to commercial sales representing such a small proportion of the total production of this class of chassis, and also due to the questionable driver acceptance and consequent care that such vehicles would receive from drivers in the average fleet.

We are in favor of limiting reasonably top road speeds of vehicles in commercial service. It is necessary, however, for them to perform creditably with other vehicles on the highways, particularly in accelerating and decelerating abilities, and they should have a high enough top speed so as not to impede or get in the way of normal traffic. They should have good power in lower gears, bearing in mind that they are work vehicles and, as such, must go places and do things not required of non-commercial vehicles.

Truck Speeds and Limitations. – The modern heavy-duty truck is becoming more and more a precision tool for application to exacting tasks. No longer do we put a 2-ton truck on a 4-ton job, or a 3½-ton truck on a 5- or 6-ton job, and let it go at that. Every phase of the job for which a truck is to be supplied receives careful analysis and consideration. The completed vehicle reflects the inclusion of its specific job requirements. Our ability to apply fine discrimination to the specification of new trucks is due to the progress that has been made by the designers and manufacturers of vehicles and equipment who are eager to improve their products and their usefulness to us.

We are better able than ever before to engineer safety into our motor trucks. Beyond this point, however, the necessity for giving greater consideration to the component parts or features of new vehicles that affect the ability to operate them in the safest and most economical manner becomes increasingly important and necessary with the generally increasing truck performance abilities and road speeds. Closer and more detailed scrutiny of new-vehicle specifications must be made.

Given the power to travel at higher speeds and to negotiate steeper hills and grades, we must be sure to supply the power to stop within reasonable distances and to control descent of the same grades. Ratios of power to weight, and of total gross to chassis weight; performance abilities on the open road and off the road in tough going; adequate wheelbases for best gross distribution; type, size, and adequacy of brakes, frames, tires, lighting – are but some of the factors that can affect the relative safety of our vehicles.

Cabs and Driver Comfort. – The driver and the crew finally have come into their own. No longer is proper provision for them ignored or given last consideration in the design and construction of new vehicles.

Cabs are closed and safety glass equipped. The best possible vision in all directions is sought. Seats and back rests must be correctly shaped, constructed, and located with reference to controls. Driver fatigue contributes to the possibility of accidents. Good cab and body ventilation is required. Power brakes and brake amplifiers to provide greater effectiveness and reduced pedal pressures are desirable and necessary on all except our lightest trucks. Adequate windshield wipers are a requisite. Windshield defrosters have come to be a fundamental requirement in many parts of the country,

as have heaters. Fellow employees are not permitted to crowd the driver.

Cabs to accommodate the driver, foreman, and crew represent the latest body development on work or construction trucks. A special cab provides seating accommodations for the personnel normally assigned to the vehicle, affording protection from the weather and from the hazards of riding the load. For a six- or seven-man crew this seating arrangement requires an additional full-width seat behind the driver that increases the depth of the cab 30 in. A close-up of such a seven-man cab is shown in Fig. 1. In line-construction trucks, the winch is moved back and the aisle is shortened this distance. Tool and material compartments are carried forward alongside the special cab. They are of the same length as on a truck equipped with a conventional cab. Wheelbase and overall length of similar bodies equipped with either conventional or seven-man cabs are the same. This development represents a substantial contribution to special-purpose truck design.

Bodies and Equipment. – Adequate provisions for safety can be engineered into new truck bodies and equipment.

Floors are low and roofs are high to facilitate easy loading and to provide good head-room. Aisles are wide. The aversion to wheelhouses in other than platform bodies has largely disappeared to obtain the advantages of lower floors. Stake side sections are small and light weight for easy handling. Fixed sides are as low as possible. Heavy tools and materials are carried low to minimize loading effort. Means are provided to fasten loads adequately and prevent shifting. Unnecessary or hazardous projections of body and load are taken care of in so far as possible in the design of the completed vehicle.

Safety-tread steel or aluminum is being used for floors and tail gates. Fronts of express-type bodies are closed and equipped with ventilators for the greater comfort and protection of men who ride with the load. Closed body interiors are painted in light colors to improve visibility.

New public-utility trucks are provided with rubber-covered ladder irons and bumper blocks to safeguard against splinters. Ladders or steps to platforms and towers are of self-cleaning safety-tread material. Heavy towers are power- instead of hand-elevated, with top and bottom limit switches on tower travel. Platform railings are high and of light-weight construction, easily raised or collapsed. Most of these features are illustrated in the rear view of a modern conventional overhead-lines truck shown in Fig. 2.

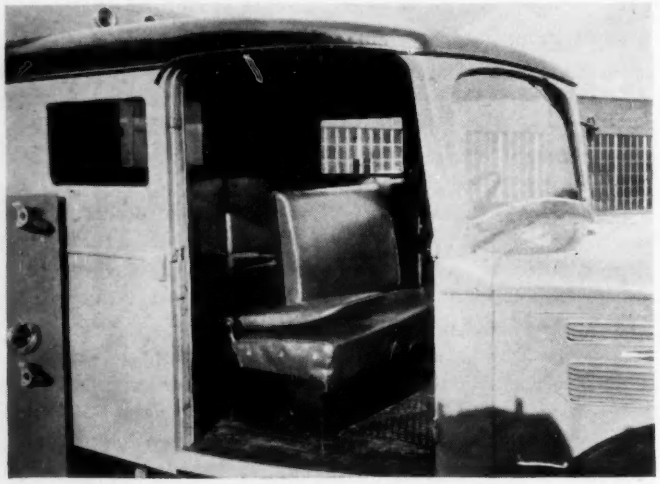

Fig. 1 – Interior of Seven-Man Cab as Mounted on Special Overhead-Lines Truck

Note front seat cutoff and folding back-rest to facilitate entrance to rear-cab compartment. Left section of rear seat collapsible for emergency exit to rear of body.

Safety from a Maintenance Standpoint

How well are motor vehicles maintained in the United States and what percentage of accidents is due to defects in the vehicles involved in accidents? To use an expression of one of our famous statesmen, "Let's look at the record". The National Safety Council tells us that:

"Defects of the vehicle itself are estimated to cause or help to cause at least 15 per cent of the accidents. The most important vehicle defects are defective brakes or deficient or glaring headlights. As with unsafe highways, however, the careful, skillful driver can generally avoid accidents even if his vehicle is somewhat defective".

The Travelers Insurance Co. is authority for the statement that 94.9 per cent of motor vehicles involved in accidents during the year 1935 were apparently in good condition. If this statement be true, it means that only 5.1 per cent of the vehicles involved in accidents were mechanically defective.

The State of Oklahoma has been waging a war against highway death and its State Highway Department has been gathering statistics in order that it might properly direct its efforts. The records indicate that the number of defective vehicles involved in accidents in which persons were killed or injured in the State from October, 1935, to February, 1936, inclusive, were as follows:

	Number of Accidents	Percentage
October, 1935	17	11.1
November, 1935	12	9.7
December, 1935	15	9.8
January, 1936	12	11.5
February, 1936	8	8.1

The City of Evanston, Ill., has done an outstanding job in motor-vehicle accident-prevention work. It has compulsory inspection of vehicles, conducts driving schools, and keeps good records of accidents and their causes. We asked A. R. Forster, Director of Public Education of Evanston, what part defective vehicles played in accidents that occurred in their city and here is what he said:

"As regards the number of accidents chargeable to defective cars, no accurate and reliable figures can be given. The available statistics are admittedly inaccurate due to the fact that the condition of vehicles after accidents often precludes the possibility of determining their condition prior to the accident. The following figures which are undoubtedly very far below the actual percentage indicate the percentage of vehicles involved in accidents in Evanston in the past three years that were found to be defective in one or more safety features, chiefly brakes and headlights:

1933	3.3 per cent
1934	2.3 per cent
1935	1.6 per cent

A report made by W. S. Canning, Engineering Director of the Keystone Automobile Club, to the Highway Research Board, Department of Traffic, Washington, D. C., at their annual meeting Dec. 5, 1935, gives us the following answer in reply to the question "Are mechanical defects an important factor?":

"We find that about 5 per cent of all vehicles registered

were involved in accidents, that about 3.2 per cent of the accidents were attributable to mechanical defects, and that less than ¼ of 1 per cent of all the vehicles registered were in accidents attributed to mechanical defects."

As of Jan. 15, 1935, nine States required periodic inspection of motor vehicles. They were:

State	1934 Motor-Vehicle Registration	Number of Inspections Per Year
Delaware	54,240	2
Maine	178,995	2
Maryland	332,892	1
Massachusetts	785,392	1
New Hampshire	113,134	1
New Jersey	864,641	Upon proclamation
New Mexico	82,900	3
Pennsylvania	1,681,202	2
Virginia	373,908	2
Total vehicles registered	4,467,304	

During 1935, nine more States passed compulsory or permissive legislation during the year. They were:

State	1934 Motor-Vehicle Registration	Number of Inspections Per Year
Colorado	274,231	2
Connecticut	357,787	2
Illinois	1,456,241	Municipalities of 40,000 population or over
Iowa	666,440	All municipalities
New York	2,269,355	Buses and school buses
Oregon	274,117	Cities of 100,000 or more (Portland)
Tennessee	336,313	Memphis
Utah	101,926	
Vermont	77,921	
Total vehicles registered	5,814,331	

Not all of the States in either of the preceding groups have accident records showing the number of accidents attributable to mechanical defects. Such figures as were obtainable from all sources having statistics believed accurate are herewith summarized for the year 1934:

State	Motor-Vehicle Registration	Total Vehicles in Accidents	Accidents Caused by Mechanical Defects	Per Cent Mechanical Accidents
Massachusetts	785,392	65,976	605	0.92
New Hampshire	113,134	3,265	88	2.70
New Jersey	864,641	56,511	2,433	4.31
Pennsylvania	1,681,202	83,724	4,028	4.81
Connecticut	357,787	26,323	550	2.09
Virginia	373,908	17,509	823	4.70
Total	4,176,064	253,308	8,527	3.37

From the foregoing, it appears that about 3.37 per cent of all vehicles involved in accidents during the year 1934 in the six States shown were determined to have been mechanically defective. The low percentage of defective vehicles involved in accidents should not cause us to decrease our efforts to improve our maintenance. There is still much to be done in this regard. Let us turn for a moment to the records of the city of Evanston, Ill., and see what their inspection of vehicles in 1935 disclosed:

Total inspections made 46,020

Reasons for rejections:

	Number of Vehicles	Per Cent of Vehicles Inspected
Headlights	6331	13.7
Brakes	5724	12.5
Wheel Alignment	4320	9.4
Tail Light	666	1.4
Windshield Wiper	600	1.3
Steering	267	0.6
Horn	123	0.3
Rear-View Mirror	77	0.2

If vehicles are maintained and inspected properly, the defects just reported would have been rectified assuming, of course, that work was performed properly. Economy of operation, good maintenance, good inspection all go hand in hand with safety.

Mechanical Faults in Commercial Vehicles. – It has been established clearly that mechanical defects in well-maintained fleets are rarely responsible for accidents. In our own companies, it is difficult for us to recall cases where the condition of the vehicle was such that it was the cause of, or contributed to the cause of, an accident.

Preventive Maintenance Required for Safe Operation

It is not possible to present fixed rules for governing frequency of inspections as the nature of the operation must govern such frequency. Our experience has been that education of those making the inspections to insure their attention to details is of utmost importance. The average mechanic will make a good mechanical check-up. Special training, however, is necessary in order properly to check lights, horn, windshield wiper, heaters, defrosters, and so on – all items intimately associated with safety.

Night Driving Most Hazardous. – Statistics indicate that night driving is four times as dangerous as daytime driving, 56 per cent of fatal accidents occurring during the night. Fatal automobile accidents at night have been increasing steadily during the past five years, while fatal accidents during the daylight hours have been decreasing. Generally, this increase is no doubt attributable to fatigue and to an easing of the precautions that are taken in times of greater traffic density. Specifically, it may be influenced by the repeal of prohibition and an increase in drinking.

Fig. 2 – Conventional Overhead-Lines Truck – Rear View

Showing roof construction, body jacks, rear steps, top and bottom sheave bars, double-drum winch cover, and method of enclosing pike-pole points. Note method of carrying pole derrick and power reel.

We feel that the increase in night-time accidents is due to drivers "over-driving" their headlights. If high speeds are to be employed in night driving, we must have better light, either through improvement of the lights on the vehicle or through lighted highways.

Pending the arrival of these improvements, we can improve on the maintenance of our present equipment. Head-lamp reflectors should be cleaned and polished at least twice each year, at which time lamp globes should be replaced if necessary and lamps should be adjusted properly.

Tire Pressures. – The air pressure in tires must be checked and maintained carefully to insure proper stability of the vehicle, especially at high speeds.

Lubrication. – Lubrication of the entire vehicle is of importance in its relation to safety. The vehicle properly lubricated will handle better than the neglected one. Also, the rate of wear of parts will be reduced to a minimum. In this connection, the person doing lubrication work should be trained to inspect the vehicle as he lubricates it, tightening loose nuts and bolts, replacing missing cotter pins and calling to the attention of his superior any condition of the vehicle that he believes would contribute to an accident.

Replacement of Worn Parts. – It goes without saying that good maintenance practice insures the replacement of worn parts before such parts can contribute to or cause accidents.

Exhaust Leaks and Fumes. – The elimination of exhaust-gas leaks caused by defective gaskets, manifold, exhaust pipe, mufflers, or heaters is very important. Many accidents have been caused through defects of this nature.

The Driver

Regimentation has little place in our efforts to promote safer vehicle operation. Whether or not at fault in accidents in which they become involved, drivers expect that fair and courteous consideration will be given to the circumstances surrounding the occurrences. Viewing an accident through their own eyes they, of course, are not very often responsible for it. As a result, the investigation of specific accidents must be thorough and complete. There must be no doubt in the mind of the driver's superior as to responsibility. Once it is established that a driver is responsible, discipline should be sufficient to have the particular driver guard against a recurrence, even to the extent of lay-off, demotion or, in extreme cases, service severance, the last action primarily for its effect upon other drivers. Experience has shown that driver care is in proportion to the significance that management attaches to an accident-free operation.

Variety in the type of facts, and in the form of safety material presented to driver groups, must be employed if we are to maintain active interest. Preaching can be overdone readily. The commonplace has but little appeal.

Concurrent preventive and corrective measures are necessary and desirable. A general preventive activity should be carried on for the assistance of all drivers and, at the same time, constructive corrective measures should be directed toward those involved in accidents.

Accident Classification. – Accidents should be classified by types to permit prevention attention in proportion to relative frequency or severity. As an illustration, collisions of a company's vehicles with a stationary vehicle or object were responsible for the greatest number of accidents in a recent period. In the same period of the preceding year the highest number of accidents were in the classification of struck-while-parked. Segregation of accidents by types affords the opportunity to stress the prevention of those currently predominating.

A New Type of Accident-Report Form. – The need for an accident-report form that would satisfy not only the needs of the claim adjuster in describing *what* had happened, but would also, by its makeup, record the circumstances that led up to the accident and tell *why* it happened, has been felt for some time. Such a form, now being used by our Pittsburgh companies, is shown in Fig. 3.

Heretofore, it has been the practice of the claims department or insurance company to design the accident-report form on the basis of claims defense and adjustment requirements. No particular attention was given to operating requirements. If the operating superintendent is to discipline, train, or re-instruct drivers intelligently, he must know their operating faults. This report form has been designed with this purpose in mind.

Many commercial fleets rely entirely upon the report of the driver. The claims department or insurance company should provide operating departments with abstracts of the facts surrounding the occurrences as given by disinterested witnesses or investigators.

Claims men should be taught to investigate for prevention as well as for claims defense. Too often minor accidents with major faults are passed by without action because the claims agent does not bring the facts that he has established regarding the causes of accidents to the attention of operating officials. Also, in his haste to make an adjustment, the claims man sometimes overlooks or does not bring to light major faults or failures. The claims man is in a peculiarly splendid position to aid the operating men if he will assume the additional obligation of investigating for prevention.

Motor-Vehicle Operators Manual. – None of us can produce the best result without knowing the attitude, policies, and desires of the management toward our work. This statement is no less true of motor-vehicle operation than it is of our principal occupations. A manual for motor-vehicle operators that outlines company policies and desires serves admirably for this purpose. The greatest response will result if it is written and phrased in a tone designed to be helpful and informative rather than as rules and regulations or do's and don'ts.

Control Methods in a Principally Driven Operation. – As being typically illustrative, we refer to the practices being followed by the Pittsburgh Motor Coach Co. and the Pittsburgh Railways Co. in controlling highway accidents. Here we have employees who do nothing but operate vehicles, providing the ability to measure efficiency and performance on the basis of correct and safe operation. In these companies, records are maintained that show the number and kinds of accidents in comparison with the number of hours worked. At regular intervals the individual accident rate per hours worked is compared with a group average, which comparison readily isolates accident-prone operators. Types of accidents are then studied and proper treatment applied, which treatment may involve discussion, verbal re-instruction, or actual re-training under a competent teacher. Operators have been found, with as much as 25 years of service, who lacked basic knowledge of good operating practices.

The Incidentally Driven Operation. – The matter of controlling motor-vehicle accidents in an incidentally driven fleet has its own peculiar ramifications. The approach is less direct. The methods that are used should stress safe operation as a fundamental job requirement to no lesser degree than for

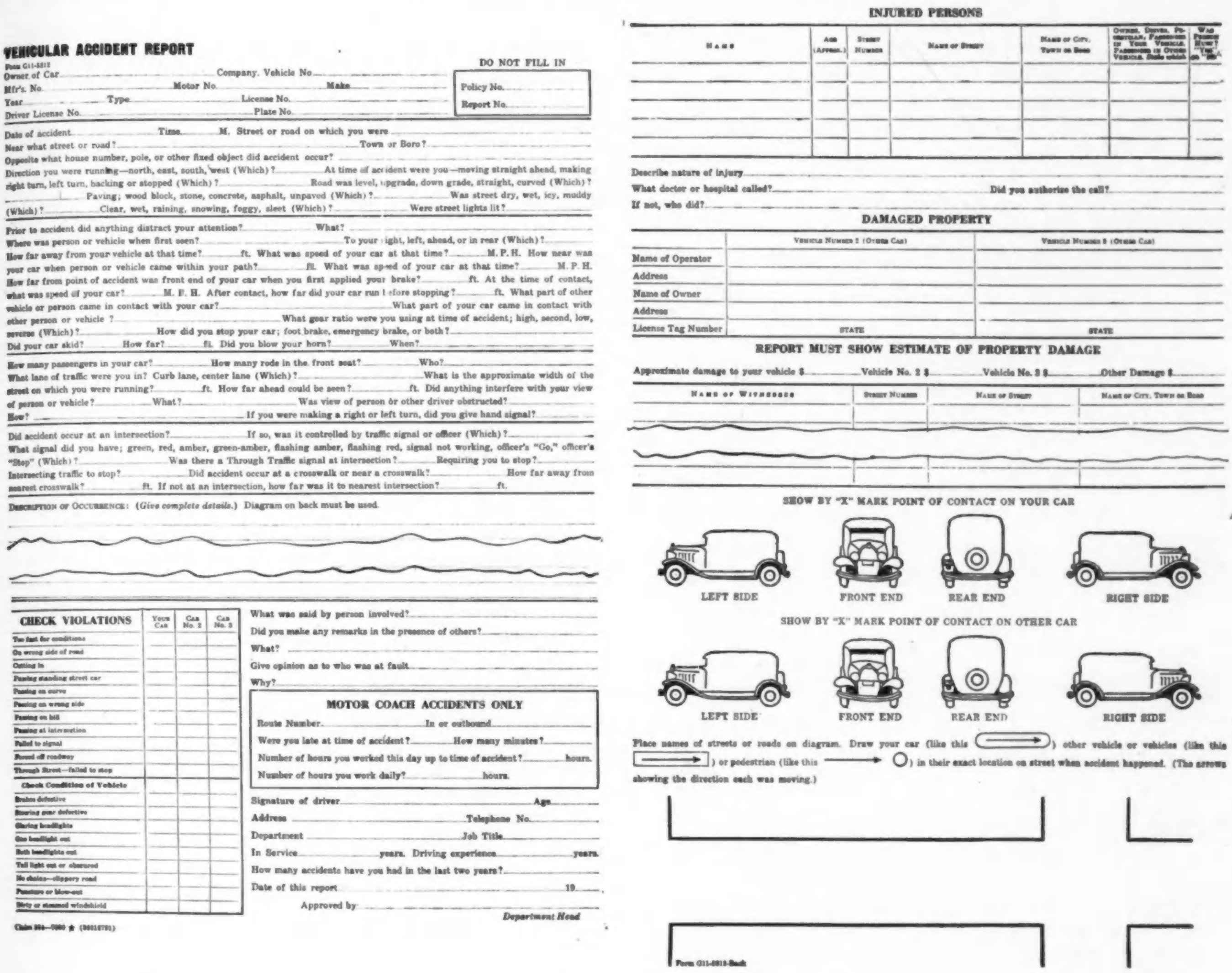

Fig. 3 – Front and Reverse Sides of Accident-Report Form That Tell Why It Happened as Well as What Happened

principal-driving jobs. They must be tempered and adjusted, however, to the fact that driving is not principal, but subordinate to their principal occupations.

Discussion of Actual Methods Being Used. – In discussing and illustrating methods that can be used to attract driver interest and cooperation in the improvement of fleet-accident experience, we refer to the experience of a public-utility fleet developing about six million miles per year with six hundred vehicles.

Fleet Experience. – Miles driven per accident of all types, from a scratched fender to a fatality, have been as follows:

		Improvement Over Previous Year
1930	12,953	
1931	14,409	11.24 per cent
1932	16,722	16.03 per cent
1933	18,128	8.41 per cent
1934	20,868	15.11 per cent
1935	23,452	12.39 per cent

Improvement, 1935 over 1930, 81.0 per cent.

Accidents per 100,000 miles were 7.72, 6.94, 5.67, 4.79, and 4.2 respectively in the periods shown.

Average frequency in 1935 was at the rate of an accident for each 24 months of vehicle operation. This is a long time between accidents. It affects the type of general appeal that can be made and the frequency and variety with which the subject can be best called to attention.

Driver Experience. – In 1935, 194 or 14 per cent of the employees licensed to operate company-owned vehicles were involved in a total of 274 fleet accidents. 85 per cent had no accidents. 152 employees had one accident each, while 42 had more than one each. 81, or 42 per cent of the drivers involved in accidents in 1935 were also involved in accidents in 1934, which data point to the probability that a part of this group is accident-prone, and that they should be studied especially.

The experience in this fleet, which is generally typical, parallels that of Dr. Lauer[1] in his extensive testing of motor-vehicle operators. He has found evidence of three groups of drivers: (a) the accident-free who constitute from 70 to 75 per cent of all operators. These people never have an accident; (b) the accident-liable who constitute 20 to 25 per cent; and (c) the accident-prone, a small minority who have the ma-

[1] Dr. Alvhh R. Lauer, Associate Professor of Psychology, Iowa State College; Chairman of the Committee on the Psychology of the Highway of the National Research Council.

jority of all accidents. Dr. Lauer says that, if a selected 7 per cent of the drivers were removed from the road, the number of accidents would decrease 50 per cent.

Development of Other Data. – Various other data can be developed that may be helpful, such as degree of severity, miles per accident per individual employee, months of operation per vehicle accident, accidents per hundred vehicles of each type per year, proportions of accidents by days of the week, time of day, age groups, and so on.

Driver's Qualifications. – Road and code tests are usually required of employees before they are authorized to operate company-owned vehicles as an assurance of competency. Company drivers' licenses are issued to those satisfying the requirements.

In our Pittsburgh operations, drivers are required to have satisfactory vision and hearing as evidenced by examination by company physicians every two years. This examination provides an opportunity for the physicians to talk to employees regarding their general health and to identify those with outstanding physical faults. Full-time drivers are required to submit themselves for a complete physical examination annually.

Responsibility. – The responsibility of this company's drivers for accidents in 1935 was as follows:

	Number of Accidents	Per Cent of Total
Wholly responsible	79	28.8
Contributed to the cause	46	16.8
Responsible accidents	125	45.6
Not at fault	149	54.4
	274	

The frequency of responsible accidents and the proportions that they bear to all fleet accidents can be followed as an indication of the comparative care exercised by fleet drivers and their ability to keep out of accidents on the highways. For instance, the drivers of this fleet were adjudged to be responsible for 49.9 per cent of all accidents in 1934, which figure compared with 45.6 per cent in 1935.

The frequency of *all* accidents, regardless of fault, should be followed as an index or barometer of progress in fleet-accident prevention. The consequences of an accident can be just as serious to the driver who was not responsible for its occurrence as to the driver who was at fault.

Methods of Determining Responsibility. – An employee operating a company-owned vehicle at the time of an accident is usually in a rather uncomfortable position until his superiors have indicated an opinion as to whether he was responsible or blameless for its occurrence. The determination of responsibility is made in various ways – by department heads, safety engineers of departments, and so on.

An effective method of establishing responsibility is by means of accident committees, appointed by the department head to investigate and determine the facts pertinent to specific accidents. Drivers meet with the committee, the facts are studied, and the committee's findings as to responsibility are reported to the department head for such action as he sees fit to take.

A routine was developed and adopted in 1934 in our Pittsburgh operations that is working out well. Shortly after an accident a form, illustrated in Fig. 4, is sent by the Accident Prevention Bureau to the head of the department to which a vehicle was assigned at time of occurrence. The department head is asked, with the return of the form, to indicate his belief as to whether the driver was wholly responsible, contributed to the cause, or was not at fault in any way. The driver's record is charged accordingly. This plan places the determination of responsibility with the driver's superior.

There are some who feel that responsibility should not be determined by the employee's department head, who naturally leans toward the defense of his own men. Considerable merit rests in this contention, based upon experience. On the other hand, friction usually develops when responsibility for an employee's actions is otherwise determined. The results in any case are relative, and it will depend upon the tenor of the organization to which it is to be applied as to which of many methods are most effective. The important thing is to have some way of determining responsibility, whatever the method.

Copies of accident-investigation reports are given to department heads for their assistance and guidance in determining responsibility. Tendencies toward accident-proneness are called to their attention.

Recognition of Safe Driving. – Many plans for the recognition of safe driving are in effect. These methods include certificates of various kinds, buttons, badges, cards, and so on. Bonus systems are used in some full-time driving jobs, but rarely in incidentally operated fleets. I would like to describe a simple and effective means that is being employed by us:

With the annual renewal of an employee's license, Honor Operators' Licenses are issued to employees who have driven for one or more consecutive past years without a responsible accident. The card bears the notation in red, "Honor Operator, No Responsible Accidents, — years". A responsible accident at any time wipes out the employee's past good record so far as this form of recognition is concerned, and he must start over again to establish one for a new unbroken period. We have had many evidences of the good effect of this method.

Employees who drive considerably are proud of a safe-driving record, and of any definite official recognition that is taken of it. They are pleased to receive an Honor Operator's License. As the number of years builds up, greater care is taken to preserve a good record. Increased concern is felt as to whether they are to be judged responsible when accidents occur.

For those who are statistically minded, I include a tabulation showing the number of employees in our companies who, upon being licensed for 1936, were given 1- to 7-year honor cards. Our use of this plan began in 1929.

7 years (1929-1935, inclusive)	229, or	15.0 per cent
6 years (1930-1935, inclusive)	143, or	9.4 per cent
5 years (1931-1935, inclusive)	152, or	10.0 per cent
4 years (1932-1935, inclusive)	156, or	10.2 per cent
3 years (1933-1935, inclusive)	198, or	13.0 per cent
2 years (1934-1935, inclusive)	256, or	16.7 per cent
1 year (1935)	176, or	11.5 per cent
Not entitled to honor license due to accidents in 1935, or because licensed for first time in 1936	217, or	14.2 per cent
	1527	100 per cent

Safety From the Standpoint of Design

It was not intended originally to deal with the matter of design in this paper. However, as operators of a large number of vehicles, we cannot help but observe that, from a safety standpoint, our modern automobiles leave much to be desired.

The subject would make a paper in itself, hence, all we can do at this time is to present a few high lights in question form:

Visibility. – Is it possible for the driver to see the edges of the right- and left-front fenders?

We feel that inability to do so in most of the new cars has been responsible for vehicles having been driven off the roads on to soft shoulders. Also, it has been the cause for vehicles side-swiping others going in the opposite direction. The driver was not able to see nor to judge just where his car really was or how it was headed.

Can the driver see out of the windshield without slumping in the seat or stretching his neck?

Drivers' seats, adjustable frontwards, backwards, and vertically are essential.

Can the driver see an object 25 ft. ahead of the car?

Sitting too low, too much hood, huge front fenders, high cowls – all contribute to the inability to see an object very close to the vehicle.

Is vision obstructed by corner posts?

Blind-spots due to this cause are difficult to eliminate, but more attention must be given to this structural problem.

Is the rear-view mirror of such size and so located as to make it possible to see to the rear, or is it just a convenience for the ladies to aid them in their make-up?

We have seen some rear-view mirrors that actually interfered with forward vision and were in no sense adequate for a view to the rear.

Roadability. – Does the car act stable at all driving speeds? How does it act on loose gravel, rutted-muddy roads, on ice- or snow-covered pavements, and on wet pavements? Does it travel in a true course, or is it necessary to fight the wheel constantly? How does it handle on curves? Does the rear end stay on the pavement when rough roads are traversed? How does it handle in cross winds?

These factors are all pertinent to safety and we are of the opinion that a great many of our new cars would show up poorly or fail in most of these tests.

Steering. – Is it easy to over-steer?

The design of steering gears and ratios employed in the newer passenger cars are conducive to over-steering. Paradoxical as it may seem, high numerical steering ratios are safer than lower ratios; in fact, it is believed that we could safely go as high as 22:1. The obvious reason for this belief is that over-steering by the driver is minimized. Higher ratios would also reduce the practice some operators have of cutting in and out of traffic lanes at a sharp angle and at high speed. It is needless to point out the danger involved.

It is to be admitted that higher numerical ratios result in a slow steering gear and affect maneuverability adversely. This factor is of little import in view of advantages gained.

Comfort. – Are the front and rear seats wide enough to accommodate three full-sized adults wearing winter clothing?

The minimum width of the seat cushion should be 48 in. to accommodate three people comfortably and safely.

Is there enough head-room?

Some body stylists have reduced head-room for the sake of low, sleek appearance. Severe head bumps or even broken necks may result from this trend.

How is the accelerator pedal located? Does it provide a natural, comfortable position for the driver's foot and leg?

Driver fatigue caused by illy located accelerator pedals contributes to accident-proneness.

Ventilation. – Is it possible to cool and heat the interior of the vehicle properly and still change air sufficiently often to promote the requirements of good health?

We believe that many accidents have been caused not by carbon-monoxide but by carbon-dioxide poisoning. The vehicle was not properly ventilated, the air became warm and stale, drowsiness overtook the driver, and an accident occurred.

Fresh air is just as essential in an automobile body or truck cab as it is in any of the rooms we live in. Some of our newer ventilating schemes in passenger cars and trucks produce a lower pressure within the body than on the outside. The result is that infiltration of engine fumes is likely to occur.

Doors. – How are the doors hinged?

In the interest of safety, they should be hinged at the front. Incidentally, the trend away from protruding door handles is good.

Lights. – High-speed driving requires better road lighting than we now have. Most of us "over-drive" our headlights at night. We prefer tilting both the right and left beams rather than only the left beam as seems to be customary in some of the new cars. The reason for this arrangement is that, at night, oncoming vehicles invariably flick their lights as a signal to dim when only the left beam is depressed. We feel that there is room for the development of a suitable road light to be mounted beneath the right headlight to illuminate the edge of the road and, further, to provide good illumination at a low enough level so that it will not interfere with oncoming vehicles.

Glaring headlights of oncoming vehicles continue to menace seriously the ability to drive safely at night. While this situa-

Date ______________

RESPONSIBILITY FOR VEHICULAR ACCIDENT

Mr. ______________________

____

Re:Accident No.____ Date ____ Vehicle No. ____ Driver ______________
Accident Location ____
Report states that

From your investigation and knowledge of this accident, will you please advise me in the space below whether you believe that our driver by his actions contributed in any way to its occurrence. Your opinion will be of primary consideration in rating our driver's responsibility.

____
Transportation Manager

This driver's previous accident record is as follows:

Number of Accidents from Jan. 1, 1931 to Dec. 31, 1933 ____________
Number of Contributory and Responsible Accidents since Jan. 1, 1934 ____________

DETAILS OF ALL ACCIDENTS WILL BE FURNISHED UPON REQUEST OF THE DEPARTMENT HEAD.

____
Transportation Manager

From our investigation of accident no. ____ Date ____ our driver's record should be charged as follows:
He was wholly responsible............................
He contributed to the cause of the accident ....
Nothing could have been done by him to prevent this accident. He is not at fault in any way.........

REMARKS:

SIGNED ______________________ DEPT. ______________ DATE _______

Fig. 4 – Form Used To Fix Responsibility for Vehicular Accident

tion has been improved some by the design of headlights, reflectors, and car or cab design in recent years, means and methods of further improvement should be sought after actively and aggressively. Special glasses for windshields and windows may assist in the solution of this problem. The further suggestion is made that spectacles, equipped with glare-reducing or glare-eliminating lenses if of a type or formula of glass that will not further reduce low night visibility, would provide a simple, effective manner of making night driving safer. The susceptibility to glare varies with individual drivers, many of whom dread night driving for this very reason. This condition is worthy of extensive research in the interests of safer operation.

Power. – Does the engine develop sufficient power to give adequate performance?

In recent months the automobile manufacturers have been censored by certain interests for building vehicles capable of very high speeds. The truck manufacturers, on the other hand, have been criticized and, in some States, laws have been passed setting up minimum-performance requirements. Every motor vehicle should have sufficient excess power to insure a satisfactory safety factor. The vehicle with sufficient ability to accelerate rapidly and pass other vehicles quickly and to climb hills with agility, will be the vehicle that will keep its drivers out of trouble.

General. – Brakes, safety glass, and body construction are all features of paramount importance in promoting safety. However, the part they play is recognized so universally that mention of them here seems unnecessary.

State Line Differences. – These United States of ours, from the standpoint of uniformity of motor-vehicle regulations, are in reality a half a hundred separate principalities. If there is doubt in anyone's mind as to this condition, we refer them to George Hook's paper[2]; to a comprehensive analysis of conflicting State requirements presented by Pierre Schon[3] at the recent Transportation Conference in Detroit; to the truck and equipment manufacturers; or to fleet managers whose vehicles operate interstate or in several States.

Safer operation will result as State motor-vehicle code requirements, both as to vehicles and drivers, become more uniform. Material progress would result from:

(1) A uniform and universal drivers' license law.

Drivers should be physically and mentally competent; they should be generally familiar with motor-code requirements, and specifically with those affecting safe operation; they should be able to operate safely and correctly the specific type or types of vehicles for which a driving license is sought – all as determined by qualified examiners.

Assurance of financial responsibility should be required of drivers or vehicle owners. Laws assuring the State of financial responsibility, or compelling all vehicle owners or operators to carry adequate insurance should be in effect in all States. Lacking this assurance the use of automobiles should be prohibited until judgments against their owners or operators, as a result of accidents, have been satisfied. Several States have enacted laws to this effect, one of the most recent being Kentucky, in which a new Driver's Financial Responsibility Law became effective May 15, 1936.

(2) Enforcement methods that identify the accident repeater and habitual violator, a central cumulative recording of individual violations, and automatic license suspension or revocation after a given number of "at fault" violations per year or period.

(3) Uniform and universal compulsory periodic inspection of all motor vehicles. Uniform brake-ability requirements.

(4) Uniform National traffic signs and signals.

(5) Uniform requirements for headlighting, identification, clearance and marker lights and reflectors, flares, and other equipment safety features.

(6) Adequate highway lighting.

Appropriate to the subject of highway lighting are the remarks of Gov. Harold G. Hoffman of New Jersey as published in *Liberty* and the *Electrical World,* May 9, 1936:

"Very few communities spend over $1.50 per capita for public illumination – and our economic waste from night motor accidents runs around $12 per capita. When you realize that one public hospital in Detroit reported an outlay of $300,000 in 1931 for night emergency motor cases alone, it ought to be clear that the taxpayer pays for street lighting whether he gets it or not.

"At the present time we are laying out upward of three billion dollars a year for the extension and maintenance of public highways and, depression or no depression, we now boast of 110,000 miles of improved highways in this country. When you consider that only about 400 miles are lighted – most of them poorly – it hardly seems unreasonable to suggest that we spend a few millions less on roads and more on lights."

Conclusions

It has been estimated by the American Petroleum Institute that, compared with the 26 million vehicles registered in the United States in 1935, there will be 29 million in 1940, 34 million in 1950, and 37 million in 1960, an increase of 11 million vehicles, which is 43 per cent, in the next 25 years. The Institute believes that the number of miles traveled each year per car will continue to increase.

If these estimates, or any that are at all similar, are borne out by experience, there is a big job ahead. Many miles of highways must be modernized, and many more miles of new highways will have to be built. Through traffic must be carried away from our congested metropolitan centers of population. Super highways – today on paper – will be the realities of tomorrow.

Order must come from the chaos of conflicting State requirements.

Drivers must be qualified before being given freedom at the wheel.

"Engineering, education, and enforcement" are three words that have become synonymous with motor-vehicle accident prevention.

There is no question as to the ability of the engineering profession to meet today's problems and to plan adequately for the future, provided that it is given a green light and the funds with which to execute its plans.

Education should have a most prominent place in plans to make our highways safer. Carefully planned safety material should be included in the curricula of every school in the land. It should start in the formative elementary grades and be carried through high school.

And last but by no means least, there must be enforcement! A substantial improvement could be made immediately if present motor-vehicle regulations pertaining to safe operation were really enforced.

Nature never tears up the ticket. Let's all drive safely!

[2] "How State Regulation Has Affected Motor-Truck Design Developments", by George T. Hook, presented at the Semi-Annual Meeting of the Society, White Sulphur Springs, West Va., June 1, 1936.

[3] "Truck Engineering Problems", by Pierre Schon, presented at the Transportation Conference, Detroit, Mich., March 19, 1936.

Discussion

Standard Safety Regulations Needed

—**William J. Cumming**
Surface Combustion Corp.

MY only comment regarding this subject is to call attention to the ever-increasing tendency on the part of local governing bodies to provide rules and regulations for automotive vehicles of the bus type, to make them safe for the public.

We speak from experience on this subject, having operated a fleet of buses for a considerable period, under the Rules & Regulations of the Transit Commission of the City of New York.

There has been a tendency toward resentment on the part of operating companies to a scheme such as this since it invariably provides for periodical inspection of all vehicles, with the possibility of rejection of some because of major or minor defects.

I would suggest that a body such as this one will come eventually to all large communities, and would further suggest that, interested as we all are in the safe operation and maintenance of this type of vehicle, steps should be taken immediately to select a standard set of rules and regulations which has the approval of this Society.

In some cases we have found that the New York regulations are severe to the point of destruction of mechanical units; yet, in spite of these inevitable shortcomings, we are impressed with the net result since we are assured of continuous, disinterested checks not only on the safety features of the regulations, but also on the maintenance of the vehicle.

I would very much like to see the Society take an active interest in the formulation of such rules and regulations as are necessary to the safe operation of automotive vehicles of the truck and bus type, and that will act as a guide for future regulatory bodies.

Relation of Car Age to Accidents

—**Donald Blanchard**
Automobile Trade Journal

THAT old cars are a menace to the safety of other users of the highways has been emphasized frequently in both the press and from the public platform. Moreover, safety has been one of the main reasons advanced for junking plans which factories have put into effect from time to time to help dealers clear their stocks of aged used cars.

However, because this assumption seemed so obviously reasonable, so far as we know, no attempt has been made heretofore to find out just how true it is. So recently *Automobile Trade Journal* made a small-scale survey of the facts to get some light on the subject.

Before presenting the figures, we want to emphasize that the number of accidents included in the survey was too small to prove anything. A much broader survey must be made before any trustworthy conclusions may be drawn. We stress this point to guard against the possibility of some propagandist with a pet idea to put over, grabbing the figures and using them to prove that he is right.

The results obtained in our small-scale survey suggest that the relationship between age and accidents is exactly the opposite of what it has been widely assumed to be. In other words, in proportion to the numbers of newer and older cars on the road, newer cars are involved in relatively more accidents than are older ones.

Table *A*—Ages of Cars in Accidents

Year of Manufacture	Number of Accidents	Percentage of Accidents	Percentage of All Cars in Service by Years of Manufacture
1924 and earlier	0	0.00	3.77
1925	5	1.15	2.94
1926	6	1.38	4.42
1927	15	3.46	5.93
1928	25	5.76	11.50
1929	40	9.22	15.70
1930	44	10.14	10.66
1931	30	6.91	8.19
1932	42	9.68	4.95
1933	45	10.37	7.01
1934	78	17.97	9.83
1935	104	23.96	15.10
Total	434	100.00	100.00

The figures on which this observation is based are the result of an analysis of 494 reports of accidents involving damage of $50 or more taken at random from the files of a big eastern State for the months of November and December, 1935, and January, 1936. The age of the car involved in each of these accidents was determined, and the accidents were then classified according to the ages of the cars involved. Then an estimate was made of the percentage of cars of each year of manufacture back to 1924 which were in service at the end of last year. This estimate was based on a mortality curve developed by John Scoville, statistician of the Chrysler Corp. This curve presents a National picture and, consequently, there is probably some error in applying it to a particular State. But the error is probably not large enough to invalidate its use for this purpose.

Of the 494 reports analyzed, 60 were on accidents involving 1936 cars, and these cars were not included in the figures presented in the accompanying Table *A* since there was no way to estimate the number of 1936 cars in service at the end of 1935.

Summarizing the figures presented in the table, 3.77 per cent of the cars in service during the period were built prior to 1925 and were involved in no accidents.

24.79 per cent of the cars in service were built between 1925 and 1928 inclusive and were involved in 11.75 per cent of the accidents.

39.50 per cent of the cars in service were built between 1929 and 1932 inclusive and were involved in 35.95 per cent of the accidents.

16.84 per cent of the cars in service were built in 1933 and 1934, and were involved in 28.34 per cent of the accidents.

15.10 per cent of the cars in service were built in 1935 and were involved in 23.96 per cent of the accidents.

1936 cars, which were eliminated in computing the foregoing percentages, had been on sale only three months at the end of the period covered by the survey; yet they were involved in 60 of the 494 accidents analyzed which is more than for any year of manufacture prior to 1934.

However, considering these figures with the unquestionable fact that the newer cars are inherently safer because of better brakes, tires, bodies, and so on, and also considering statistics issued by various States which show that roughly 3 per cent of the accidents are attributed to defective equipment, it seems fair to emphasize what fair-minded persons who have studied the situation know and that is that any substantial reduction in accidents can only come as the result of an improvement in driving habits. Certainly it seems clear that the industry's efforts to promote safety should be focused on this objective.

Driver Education and Supervision Stressed

—**H. O. Mathews**
Illinois Bell Telephone Co.

MUCH educational work is necessary with law-enforcing agencies on what really constitutes fast driving. So many municipalities, particularly those which are suburbs of large cities, would have you believe that their city limits and, therefore, their jurisdiction cover all the highways in the county. They take this opportunity for financial gain, rather than with any thought of reducing accidents. In my opinion speed should be governed more by the conditions of traffic than by somebody's pet idea. The fact that the State Highway Departments of many States are required to keep the familiar sign "Warning, Speed Trap" posted at many small towns is evidence of the need of education on this subject.

Factor Conducive to Safe Motor-Vehicle Operation.—In connection with vehicles that are incidentally operated, of which we have many, there is considerable room for improvement from the management side. Neither the drivers nor their supervisors are responsible to the motor-vehicle supervisors and, therefore, many of them are not naturally interested in operating costs, condition of equipment, and so on. In this case management should insist that safe and economical driving is as much a part of their job as the actual work they do. If this job were done considerably more progress would be made in safe driving.

Most commercial-vehicle operators do everything possible to prevent accidents in selecting and maintaining their equipment as evidenced by the low percentage of accidents from this cause. What then is the answer? It is, of course, the driver; either you or the other fellow. We examine our drivers both physically and mentally; yet we have too many accidents. It seems to me to always end in the lack of continuous education and safety programs which will prove interesting.

In driving I follow a strict rule, namely, "Drive your car, the one in front of you, and the one in back of you". If followed I believe this rule will produce good results. At least it has up to this time.

Design of Two-Engined Aircraft

By Hall L. Hibbard

Vice-President and Chief Engineer, Lockheed Aircraft Corp.

IN discussing design problems of two-engined aircraft, the subject matter might well be divided into two large divisions, the aerodynamic and the structural. The time allotted to this paper will not permit the discussion of both of these subjects, so we shall confine ourselves to the aerodynamic part of the design. This statement should not lead one to believe that the aerodynamic design is, in my opinion, the most important. Structural design must go hand-in-hand with aerodynamic. Without the strong rigid structures of the modern airplane, it would be impossible to obtain the speed with the safety which we have today.

In an effort to obtain speed, the aircraft manufacturer has increased wing loadings from 10 lb. per sq. ft., common only a few years ago, to 20 and 25 lb. per sq. ft. This increase has made the take-off increasingly long and difficult, until now it has become one of the most important design considerations. This problem has been solved partially on the latest-type bimotors through the use of the controllable-pitch propeller. The latest improvement on the controllable-pitch propeller is the constant-speed propeller. This design gives approximately 15 per cent better take-off run than the controllable-pitch type and also improves the rate of climb to about the same degree.

With the ever-increasing wing loadings, however, even the constant-speed propeller soon will not produce sufficiently short take-off runs and other ideas must be resorted to.

The trailing-edge flap and the leading-edge slot will be the next devices used by aircraft manufacturers to shorten the take-off run. The present type of split trailing-edge flap does not have good take-off qualities. It will be necessary to use other types such as the Junkers or Fowler type. The Junkers-type flap has been used for take-off purposes on Junkers planes for several years and is very effective. This type, however, has a higher drag in level flight than the Fowler flap, and hence it is probable that Fowler-type flaps, or a variation thereof, will be used more generally. In the future, take-off problems will be solved by the use of boundary-layer control in conjunction with the previously mentioned devices.

Another problem of increasing importance which should be discussed in connection with take-off and landing considerations is the problem of ground-handling. With the increasing speeds obtained with the present-day transport, the matter of ground-handling becomes very important. To show the effect of this factor on block-to-block speed for airline use it will be of interest to note Fig. 1. This schedule assumes a maneuvering time of 7 min. which consists of ground-handling which includes taxiing away from the loading platform, testing the engines, and taking-off. Then at the end of the run it includes, circling the field, landing, and taxiing up to the loading platform. It will be noted that, for distances up to 100 miles, the average block-to-block speed is only 143 m.p.h. at 75 per cent power, whereas the airplane is actually capable of 195 m.p.h. at 75 per cent power. Most of this difference is due to loss of time in ground-handling. For longer distances it becomes less important, but still there is always an appreciable reduction in speed, due to this loss of time.

It is necessary, therefore, that the aircraft manufacturer study this problem more than he has done in the past. One factor, which it is believed will help, is the adoption of the so-called Department of Commerce landing gear, with the main wheels aft of the center of gravity and with a steerable nose wheel. With the airplane in the horizontal position, taxiing will be much easier; the airplane will be safer and easier to handle on the ground, hence the pilot can taxi faster and, consequently, reduce time on the ground. With this type of gear it is also impossible to nose the airplane over and it will be possible, with the aid of some braking action, for the pilot to test his engines while taxiing out to the take-off runway.

In all multimotors the propellers play a very important part in the design. Especially is this true of flight with one or more engines inoperative. It is of considerable advantage in this flight condition to have the propeller on the dead engine feather. Practically all of the propeller companies are working on this principle, and some of them already have solved the problem, although none to my knowledge has ever been actually installed and flight-tested.

There is an opinion shared by many that the drag would be reduced and single-engine ceiling increased if a brake were applied and the propeller stopped from rotating. This opinion is not in agreement with tests performed by the N.A.C.A. Recently, in order to settle the argument, a propeller brake was installed on an Electra and test flights were made. The propeller was stopped in the vertical position so that the two blades would give as little interference to the wing as possible. The result was that the single-engine ceiling was 1200 ft. less with the propeller stopped than with it rotating. Tests by another manufacturer under almost identical conditions gave practically the same result.

Since the problem of increasing speed consists of the refine-

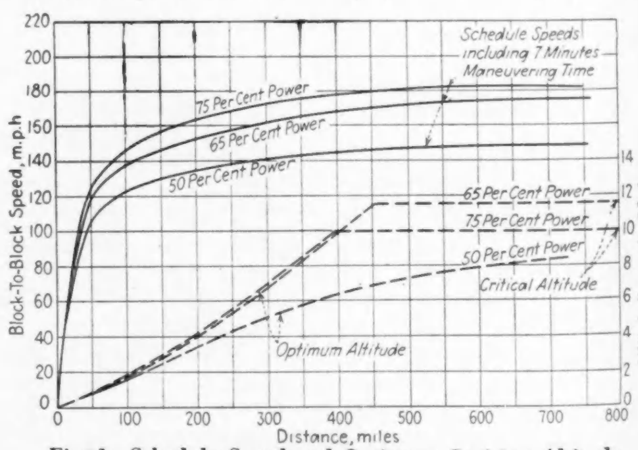

Fig. 1 – Schedule Speed and Optimum Cruising Altitude Vs. Trip Length—Lockheed Electra 10A, Full Load

Rated 800 b.hp. up to 5000 ft., zero wind. Take-off and landings made at sea level.

[This paper was presented at the Southern California Section Meeting of the Society, Los Angeles, Feb. 6, 1936.]

ment of the individual parts as well as the combined whole, it will be of interest to take some of these parts, especially the wing, and see what may be done to them to increase speeds.

In the matter of selection of high-power engines, there is no choice in this country but the air-cooled radial. This condition is unfortunate as there are many reasons to believe that for the same power the in-line air-cooled has less drag. Furthermore, it is to be regretted that the development of liquid-cooled engines in this country has almost stopped. It is hoped that such engines will be developed in the near future. Since no other high-power engines are available, we shall confine our discussion to the radial air-cooled.

First, to obtain speed even for short distances, it is of advantage to use supercharged engines. Let us study Fig. 1 again. It will be seen here that for a distance as short as 250 miles it is faster to climb to an altitude of 5500 ft., and for 450 miles the shortest time will be consumed by flying at 11,750 ft. when using 65 per cent power.

The cowling for the radial air-cooled engine is a matter for further development. Although the cowl extending straight back from the rocker boxes has been used on a majority of installations to date, there is every reason to believe that using a smaller diameter at the trailing edge is of benefit. One of the latest and neatest installations using this type of cowl is the Howard Hughes racer, which recently established a world speed record of 352 m.p.h. In order to make the drag as low as possible, the opening for the exhaust air at the trailing edge of the cowl should be as small and as flush as possible. This design reduces the amount of air permitted to flow through the cowl which also reduces the drag. On most installations of air-cooled engines at present, too much air is flowing through the cowl and not doing useful work. If the pressure baffles were made to fit tighter directing the air only to those places where it is needed, engines would run cooler with less air than they do now. This design, in turn, would permit a smaller exit area at the trailing edge of the outer cowl and low drag.

To show the effect on speed of shutting off all air from the engine and permitting none through the opening in the cowl, an interesting experiment can be related here. An Electra was equipped with tight-fitting nose shutters for cold-weather operation in Alaska. The shutters were equipped with controls such that they could be opened or closed by the pilot in flight. A test was made in flight and, with the shutters fully closed, the airplane was 5.50 m.p.h. faster than with them open.

The problem of fuselage design is one that has not received sufficient study on the part of aircraft manufacturers. In the design of an airplane, wind-tunnel studies should be made of several fuselage shapes. When looking for increases in speed these days, the designer must not overlook small changes in fuselage shape which will reduce drag. In the first place, in cross-section the fuselage must be as nearly round as possible. There should be no long flat sides and no sharp corners. It will be found often that a larger fuselage in cross-section actually has less drag if the maximum ordinate be placed in the proper location. Due to passenger accommodations on transport craft, it is necessary to have the maximum ordinate not at 30 per cent as is common with most airfoils but to have it at about 50 per cent. Fortunately, there are streamline bodies developed by the N.A.C.A. with their maximum ordinate at 50 per cent that show remarkably low drags. It is good practice in fuselage design, therefore, to follow as closely as possible one of these streamline shapes.

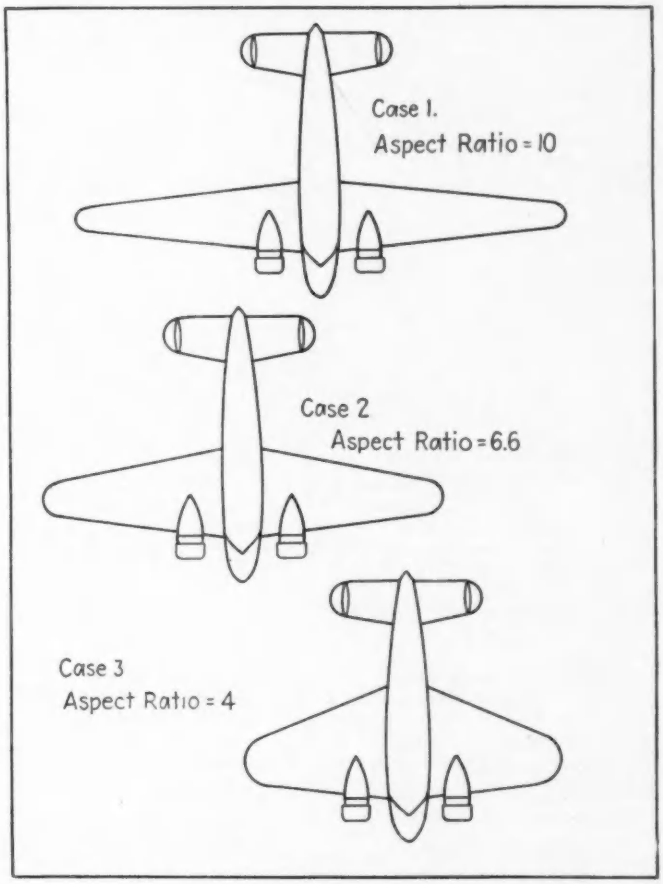

Fig. 2 – Electra Airplane with Wings for Various Aspect Ratios

Last, we should discuss the problem of the fuselage with respect to its location regarding the wing. There is one location for the wing and fuselage that gives least drag and that is the mid-wing arrangement. To date the structural difficulties of carrying the wing loads through the fuselage have been too great for the results derived therefrom and so, except in a few isolated instances, the mid-wing arrangement has not been used. The time will come when this arrangement will be used in a majority of installations, as we strive to take the last mile per hour possible out of our designs.

With the low-wing arrangement the question of the wing with respect to fuselage also resolves itself into a structural problem. If the wing is permitted to continue through under the fuselage, it is probably more simple structurally; however, if the wing be cut away and the fuselage be permitted to sink down into the wing, there will be an increase in speed. The increase in speed on an airplane similar to the Electra will be in the neighborhood of 4 to 5 m.p.h. Furthermore, if the fuselage be sunk into the wing, the probability is that no wing-to-fuselage fillet will be required. Tests indicate that fillets are required only if the angle between the top of the wing and the side of the fuselage is less than 80 deg. at any point.

The discussion of wing design is one of great importance. To choose the proper wing for an airplane one must decide the type of flying for which the airplane will be used. Will it be for short hops, long hops, or very long stratospheric flights? What percentage of power will be used for cruising? Incidentally, there has been so much talk of stratospheric flying lately that the public now has the idea that shortly we will be flying from here (Burbank, Calif.) to San Francisco in the

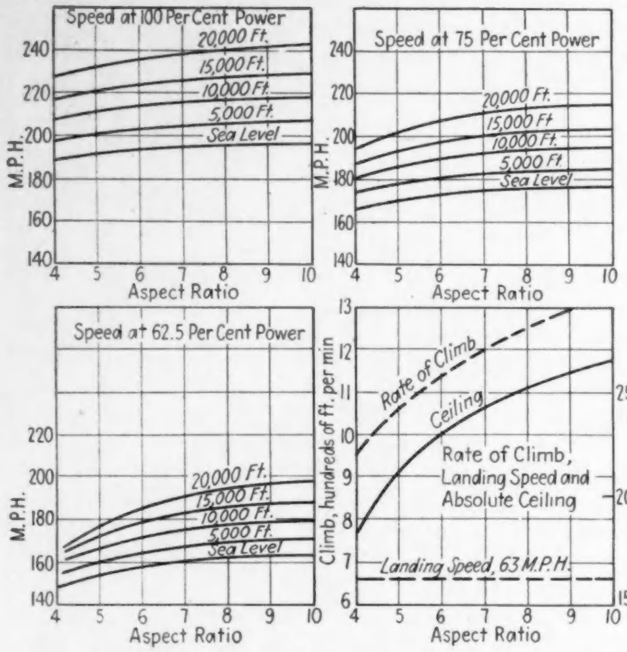

Fig. 3 – Effect of Aspect Ratio on Performance for Constant Wing Area and Gross Weight

stratosphere. This is of course not the case, as stratospheric flying will not be done on flights of less than 750 miles. The manufacturer of aircraft who is now building planes for short flights need not think that his product will be obsoleted by stratospheric equipment. There always will be a need for the low-flying type of craft for private-owner use and short-airline use.

It may appear that the following discussion on wing design is a matter of commenting on points of design that are insignificant. To those airplane manufacturers who have not already built clean designs, it is insignificant, as they have so

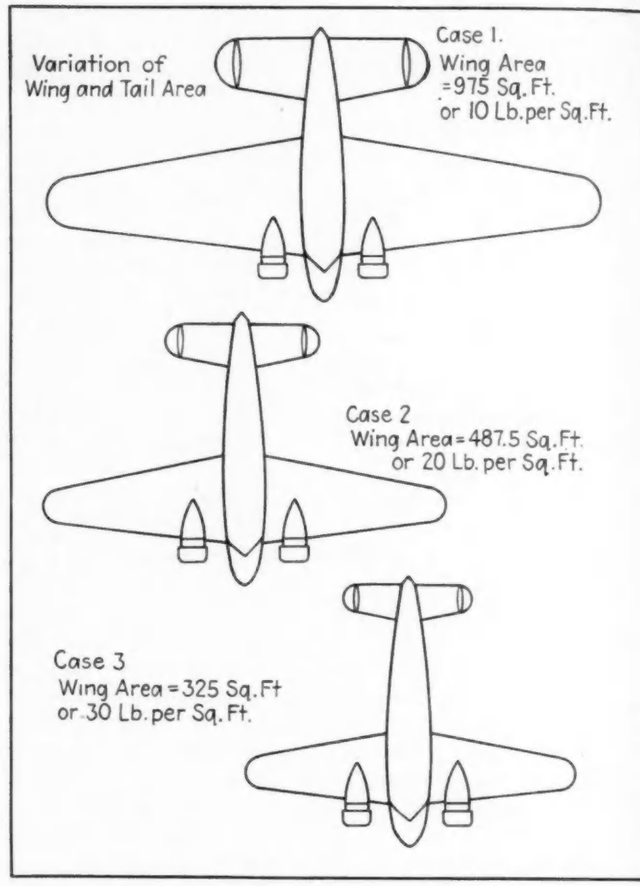

Fig. 4 – Variation of Wing Area from 325 to 975 Sq. Ft.

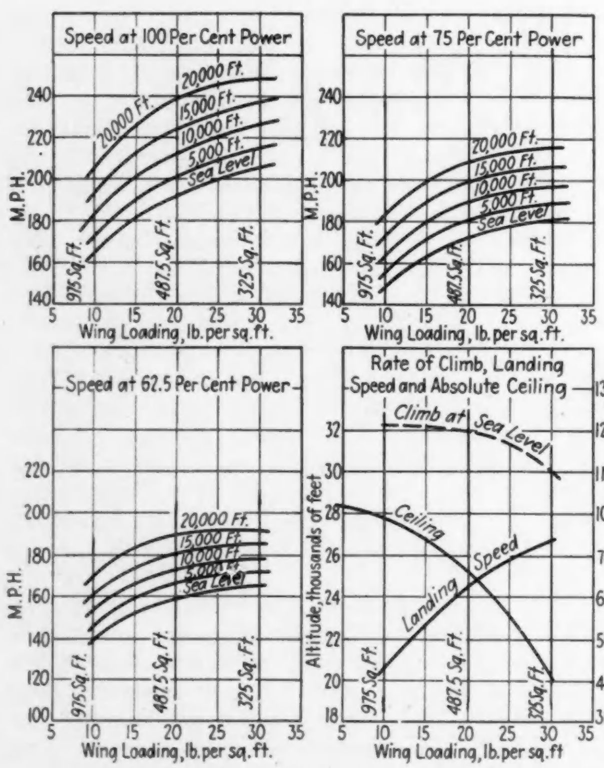

Fig. 5 – Effect of Wing Area on Performance with Constant Power and Gross Weight

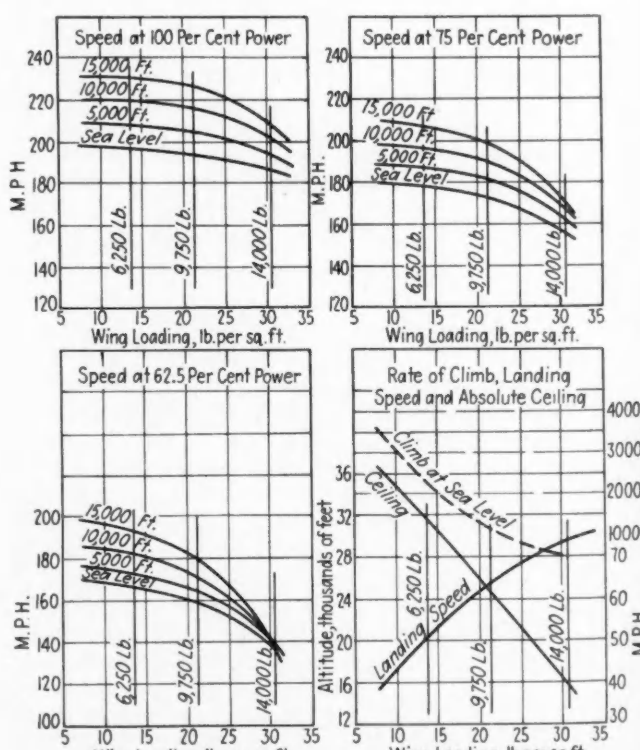

Fig. 6 – Effect of Gross Weight on Performance of Electra 10A with Wasp Jr. Engines

much to do before they arrive at the stage of design which I shall describe. The following discussion will interest those designers who have now eliminated all but the essentials from the air-stream, namely, wings, fuselage, and tail. In the quest for more speed it is from this stage that the added miles become difficult to obtain.

To illustrate, a study was made of the Electra airplane to see if any modifications in wing design would result in increases in speed. The first investigation was made on the aspect ratio has a negligible effect on speed, and then it is wings, with aspect ratios ranging from 4 to 10. The wing area and the location of the empennage are the same for all three. Fig. 3 shows a group of curves presenting the effect of aspect ratio on speed at various altitudes. I might add at this point that, although these curves have been worked out for one particular airplane, I believe the results will hold true

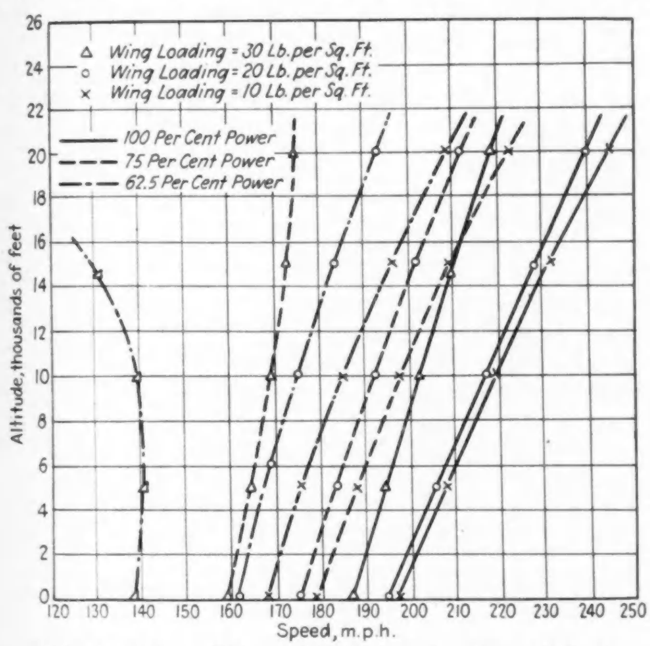

Fig. 7 – Effect of Gross Weight on Speed at Altitude
Electra 10A with various values of wind loading at constant values of brake horsepower output. Constant aspect ratio of 6.6 and constant wing area of 458.3 sq. ft.

for any other bimotors of about the same proportions, wing loadings, and power loading.

The statement has been made by many designers that the aspect ratio has a negligible effect on speed, and then it is forgotten promptly. For racing planes, which usually are always flown at full throttle, this statement is practically true as may be noted from the curves in the upper left-hand corner of Fig. 3. The curves are almost horizontal for all altitudes. However, investigation shows that, with decreased power, the aspect ratio becomes more and more important; especially is this condition true for flying at high altitude. The curves, it will be noted are steeper for the 62.5 per cent power condition than for the full-throttle condition. In other words, for an airplane designed to fly at 12,000 feet the change in cruising speed for 62.5 per cent power is 5 m.p.h., for an increase in aspect ratio of 5.5 to 8.0. The lower right-hand corner shows the effect of aspect ratio on rate of climb and ceiling. These effects are well known and need no further discussion.

Next let us examine the effect of change in wing area on performance. In Fig. 4 is shown a variation in wing area of from 325 sq. ft. to 975 sq. ft. The area of the tail surface has been kept the same percentage of the wing area in all cases

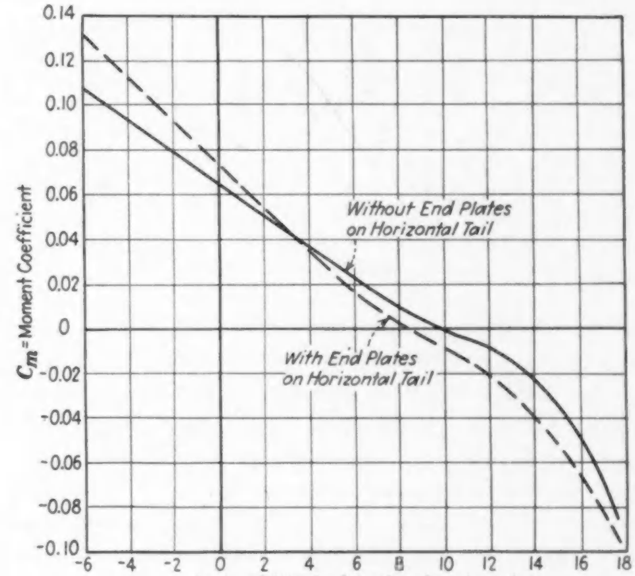

Fig. 8 – Effect on Slope of Moment Curve Through Use of Twin Fins and Rudders Acting as End Plates

although the location has not been changed. Fig. 5 shows the effect on speed of a change in wing area with a constant gross weight in all cases. Again notice the difference in slopes for the curves for 100 per cent power, 75 per cent power, and 62.5 per cent power. In this case it will be noted that the curves for 100 per cent power are steeper than the curves for 62.5 per cent power. One may see readily therefore that, no matter what the altitude, it is more beneficial for airplanes that fly at full power to reduce the wing area. In other words racing planes should cut the area to a bare minimum.

For transport planes and all other types which use cruising

(Continued on page 332)

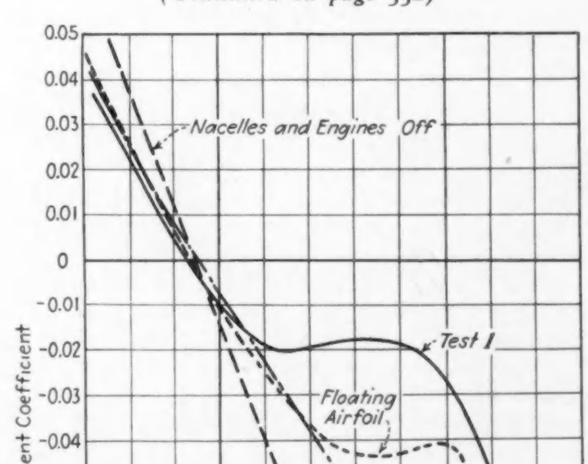

Fig. 9 – Detrimental Effect of Nacelles on Moment Curve

Cylinder Temperature

By Macy O. Teetor
Perfect Circle Co.

CYLINDER temperature is definitely one of the many important factors affecting the efficiency and life of an internal-combustion engine. Experience has indicated that cylinder temperature can be too low or too high. Each temperature extreme produces its own particular set of evils, but the high temperatures are the most destructive and the most difficult to control.

Cooling-water or fin temperature is only slightly indicative of the cylinder-surface temperatures. Since we are most vitally interested in the temperature of the working surfaces, research on the subject must start on the inside. The evils of thermal distortion are well known but probably not fully appreciated.

Practically every factor of engine performance is dependent upon lubrication. Excessive cylinder temperature destroys lubrication which, in turn, eventually shortens the life and decreases the efficiency of an engine.

An improvement in cylinder-temperature control will make it possible to increase the efficiency and life of internal-combustion engines.

THE development of the internal-combustion engine has been a continual process of strengthening weaknesses, literally and figuratively. When one element of design is improved and resulting weaknesses develop, the improvement is of questionable value until the weaknesses are strengthened. One outstanding improvement has been a constant increase in the power produced per cubic inch displacement or per pound unit weight. The additional heat generated as a result of this improvement has been increasingly difficult to handle. Failure to dissipate the excessive heat properly has either given birth to new problems or made it possible for us to re-discover some old ones. At least we have a choice of either trying to solve the many problems resulting from excessive cylinder temperatures or finding new ways and means for dissipating the heat.

To say that an engine is efficiently cooled is making a rather broad statement because of the many elements to be considered. The efficient cooling in which we are most interested at the present time is cooling that will improve operating efficiency and lengthen the life of our engines. Very little can be done with the engines already in service, but certainly serious thought should be given to the design of new engines. Considerable attention has been given to water temperatures of water-cooled engines and fin temperatures of air-cooled engines, but these temperatures are only slightly indicative of the inside working-surface temperatures – the temperatures in which we are vitally interested. Simply because the water temperature does not run over 160 deg. fahr. or fin temperature over 300 deg. fahr. does not mean that there are not excessive temperatures on the inside of the engine that will reduce the efficiency and shorten its life.

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Thermal Distortion

Almost every automotive engineer is aware of the fact that considerable thermal distortion takes place in cylinder blocks. The evils of thermal distortion in cylinder barrels have become more pronounced in the last few years because of higher speeds and more power output. This improvement in engines has increased the operating cylinder temperature. Thermal distortion that was once negligible has become a very important factor. What was once harmless blow-by has developed into a destructive force. Engine designs that at one time gave satisfactory oil consumption at 2500 r.p.m. will not operate economically at higher speeds. A large portion of these difficulties can be attributed directly to excessive cylinder temperature.

The cooling system's sole duty is to dissipate the heat, balance the temperatures, and keep them within a satisfactory range. If the cooling system does not perform this function, thermal distortion and inadequate lubrication result. Localized hot-spots are so much hotter than the rest of the cylinder surface that the differential in temperature causes terrific distortion. It is therefore almost ridiculous to spend time machining cylinder bores to a limit of tenths of thousandths of an inch if the thermal distortion of the block will destroy the accuracy under operating conditions. Thermal distortion is not limited in degree, and the resulting evils depend largely upon the amount and location of the undissipated heat. Actual dimensional change may be only a matter of tenths of thousandths of an inch, or it can develop into several thousandths. Areas operating under excessive temperature encourage lime deposits in the cooling system, which tend gradually to increase the localized operating temperature.

Fig. 1 shows a typical example of what happens to a cylinder barrel having a localized hot-spot. The high-temperature zone in this cylinder was between the valves and the cylinder barrel. The cylinder wall at this point expanded past the contour of its original shape several thousandths of an inch. The piston-rings could not conform to the distorted contour. Hot blow-by gas passed the rings at this point which increased the temperature. A heavy oil film collected on the distorted area because the piston rings could not contact the surface with sufficient pressure to reduce the thickness of the oil film. The high temperature burned the

oil which formed a layer of carbon on the cylinder wall. When an area of hard carbon is formed on a cylinder wall, it cannot be lubricated and the piston-rings cannot seal against such a surface. Under such operating conditions the piston-rings, cylinder, and piston scuff. Oil consumption cannot be controlled, blow-by is excessive, and rapid wear is inevitable.

Accurate cylinder-wall temperatures are rather difficult to obtain. The surface temperature can be recorded to a satisfactory degree by installing a thermocouple in the cylinder wall. In order to check the surface temperature it is necessary to stop the heat flow from the thermocouple to the cylinder wall as much as possible. This flow can be stopped to a great extent by mounting the thermocouple in the center of a taper pin 1/16 in. long and ⅛ in. in diameter. The pin is then driven into a taper reamed hole in the cylinder wall and honed to the contour of the cylinder. The influence of the water temperature can be reduced satisfactorily by insulating the thermocouple wires through the water to the outside of the jacket.

The surface temperature of cylinder hot-spots naturally increases with the opening of the throttle. The temperature differential between different parts of a cylinder barrel also increases with the opening of the throttle. The temperature of almost any cylinder at low speed and light load is fairly well balanced throughout the cylinder barrel. As soon as the speed and load or both are increased, the temperature of the hot-spots increases much more rapidly than the cooler areas of the cylinder barrel. It is not unusual to have a hot-spot in a cylinder barrel increase in temperature from 330 deg. fahr. to 500 deg. fahr. in 90 sec. by changing the speed from 2000 to 3500 r.p.m. While this hot-spot is increasing in temperature at this rapid rate, other portions of the barrel remain almost constant in temperature.

When this condition exists in a cylinder barrel, the accurate round shape is, of course, destroyed. The cylinder-wall temperatures indicated in Fig. 2 were taken from No. 4 and No. 5 cylinders of a multicylinder engine. At 3500 r.p.m., Point *A* in No. 4 cylinder indicates a temperature of 540 deg. fahr., while Point *C* directly across the cylinder is only 290 deg. fahr. The temperature of Point *A'* in No. 5 cylinder shows only 460 deg. fahr., but Point *B*, 5/32 in. lower than Point *A'*, is 60 deg. fahr. cooler.

Pistons and rings are designed to operate in round cylinders. When a temperature differential is set up in a cylinder barrel, it changes shape due to the difference in expansion between the hot-spots and the colder portions. The hot areas usually expand beyond the original cylinder contour. When this expansion takes place, less expansion of some other dimension must compensate for the change in shape. When the cylinder changes shape, more pressure is exerted by the piston-rings on some areas of the barrel than on others. The piston-rings are going to operate in a round cylinder if it is at all possible, and they immediately start the process of wearing off the high spots. Under normal operating conditions conventional piston-rings rotate on the piston. The piston reciprocating in the cylinder with the rings rotating in the ring grooves makes a very efficient tool for producing a round cylinder. Some of our proof that this action actually happens is obtained by careful analysis of the measurements of worn cylinders. Such wear can be correlated more directly with thermal distortion than with any other factor. Cylinders of the same design wear characteristically in the same places, and cylinders of different design have entirely different wear characteristics.

Cylinders having different thermal-distortion characteristics have different blow-by characteristics. Of course many factors affect blow-by but, nevertheless, cylinders having the least thermal distortion tend to show the least blow-by and will operate at higher speeds before the characteristic break in the blow-by curve is reached. Piston-rings are continually attempting to compensate for the thermal distortion in cylinder barrels. As long as the thermal distortion is held constant, the piston-rings have an opportunity to wear the cylinder round. When the speed and load are changing

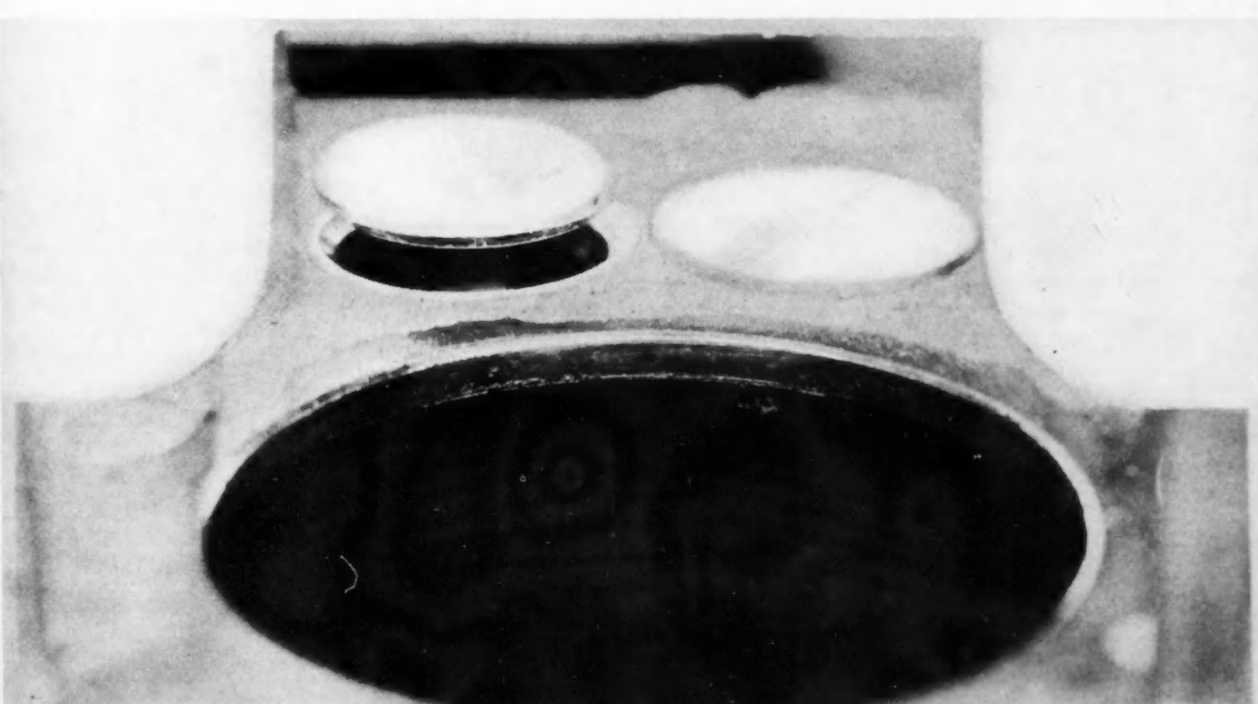

Fig. 1 – Localized Hot-Spot in the Top of a Cylinder Barrel

constantly, as they do in the normal operation of an automobile engine, the cylinders never have an opportunity to wear round.

Lubrication

The surface of a piston-ring in contact with the cylinder wall must be lubricated adequately. Adequate lubrication can be defined as a sufficient amount of oil to prevent a metal-to-metal contact between the rings and the cylinder wall. Experience indicates that, when lubrication is adequate, more lubricant is a detriment rather than an advantage because excessive lubricant thrown into the cylinders is difficult to keep out of the combustion-chamber where it burns to carbon.

Lubricant in a cylinder must serve two purposes. It serves as a sealing medium between the rings and the cylinder wall and, at the same time, separates the surfaces to prevent metal-to-metal contact. Cylinder distortion localizes excessive pressure between the faces of the piston-rings and the cylinder wall thereby upsetting the uniformity of the thickness of the oil film. There is a dimensional limitation of the effective sealing ability of oil. If the oil film is too thick, the pressure from the combustion-chamber will break through. If the film is too thin, the outward pressure of the piston-rings will break through. These two conditions can and usually do exist in the same cylinder and, regardless of what is the cause of the breaking of the oil film, the result is practically the same. Blow-by and oil consumption increase, and the surfaces of the rings and cylinder scuff.

The checking of surface temperatures in many engines shows a relation between the surface temperature of a cylinder and scuffing. The relation that has been observed indicates that, when the surface temperature exceeds 400 deg. fahr., a break-down in lubrication may be expected permitting metal-to-metal contact between the rings and cylinder wall. The resulting damage to the face of the piston-rings and to the cylinder wall depends considerably upon the operation of the engine. If the metal-to-metal contact occurs when the engine is being operated at high speed, full load, and the engine is operated for some time under these conditions, the result is usually a completely scuffed cylinder, and piston-and-ring assembly. The rings passing over the hot area scuff and carry the destruction to the rest of the cylinder which, in turn, scuffs the piston. If the operation under these conditions is of shorter duration, the scuffed surfaces may smooth up under less strenuous operating conditions. The operation of some engines is a constant process of scuffing and smoothing up accompanied by high oil consumption, blow-by, and excessive wear.

It is safe to assume that, when an area in a cylinder barrel reaches a certain temperature, something happens to the lubrication. When the oil ceases to function as a sealing medium, the high-temperature gas passes between the rings and the hot-spot. This excessive blow-by increases the temperature. When the lubrication is destroyed, more heat is developed by the friction of the metal-to-metal contact be-

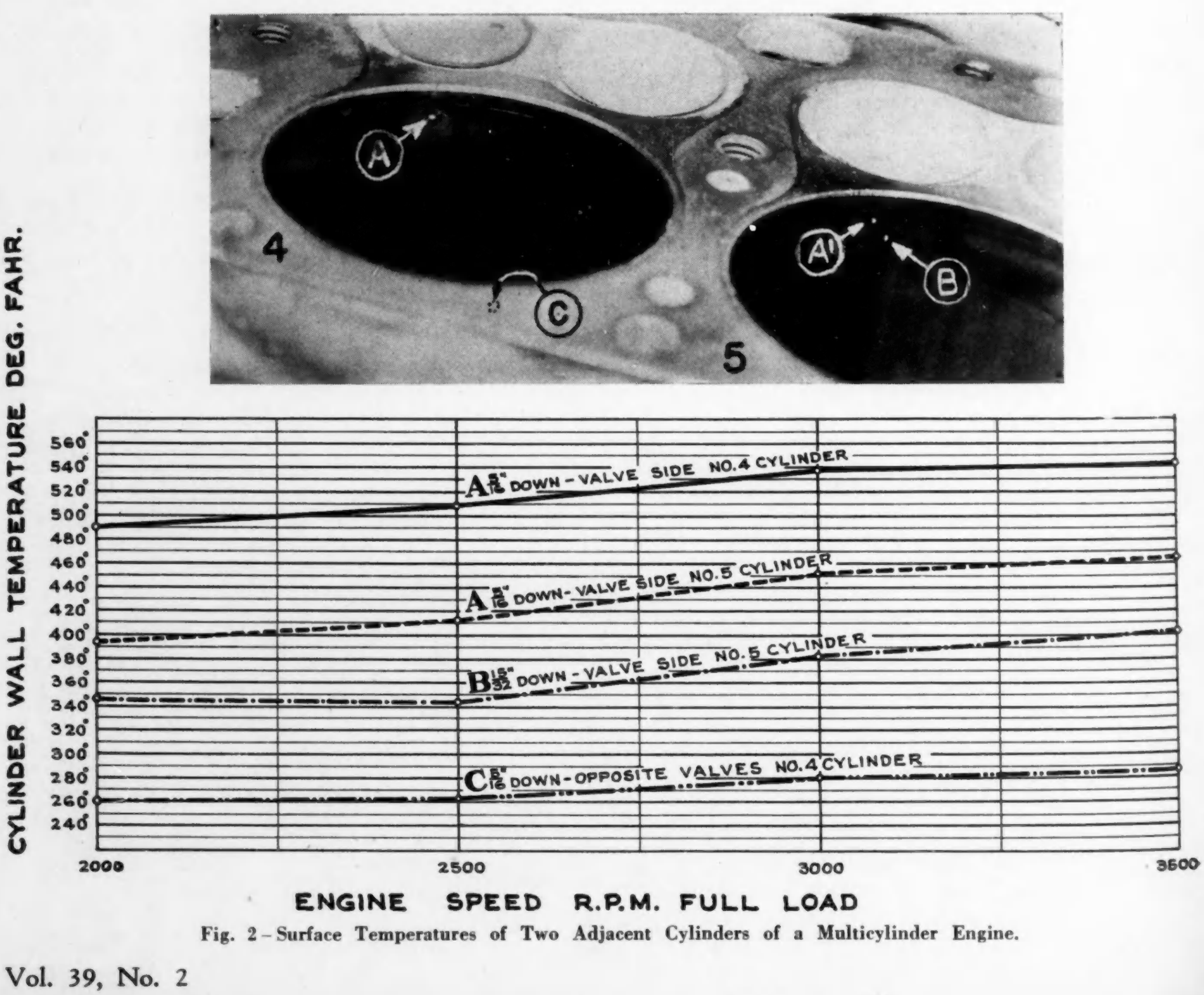

Fig. 2 – Surface Temperatures of Two Adjacent Cylinders of a Multicylinder Engine.

tween the piston-rings and the cylinder wall. Instantaneous temperatures at these points must be considerably higher than any that can be recorded with thermocouples because some scuffing indicates definitely a structural change in the surface of the piston-ring material. One way to reproduce such a structural change in the piston-ring material is to heat it to 1000 deg. fahr. We may therefore assume that these instantaneous temperatures reach 1000 deg. fahr.

Some piston-ring materials offer more resistance to dry abrasion than do others, which is probably the reason why some materials scuff worse than others. It is reasonable to believe that the ones that resist abrasion the most but still scuff, generate the most heat; these are the materials that show the greatest change in structure. When the material of the piston-ring is such that it will submit to abrasion more easily, the damage is not so serious, and the removal of material can even fall into the classification of normal wear.

The material out of which the piston-rings are made is not the only controlling material factor in the problem. Cylinders that are cast integral with the block are structurally different from top to bottom. This structural difference is caused largely by the cooling rate of the iron when the casting is made. The structure that is found at the top of the barrel where it joins the roof is different from the structure in the middle of the barrel. Just how to produce the correct structure uniformly if the correct structure were known has been a baffling metallurgical problem for a long time. About all that can be said about the problem at the present time is that the structure of the material in cylinder barrels and piston-rings has to do with wear considerably. Resistance of materials to wear has been an elusive problem for some time and, although intensive research has been maintained constantly on the subject, very little is yet known.

Fig. 3 shows the cylinder-surface temperature of three different cylinders, run on the same engine with operating conditions held as nearly uniform as possible. The thermocouple was located in the center of the top dead-center position of the top compression ring in each cylinder. Cylinder *A* was designed conventionally. The water circulation and size and arrangement of passages could be considered conventional. Cylinder *B* was produced by redesigning Cylinder *A* improving the water circulation around and between the valves. The design of Cylinder *C* is disclosed in Fig. 4. This cylinder was designed with the intention of eliminating cylinder distortion and hot-spots as nearly as possible. In attempting to eliminate cylinder thermal distortion the combustion-chamber was located in the top of the sleeve. The possible advantages to be secured from this design were greater flexibility between the roof of the cylinder-block and the cylinder barrel, and water circulation around the cylinder the full length of the area traveled by the piston-rings.

The surface temperatures of Cylinder *A* were excessive, well above what experience indicates to be safe. Scuffing to some degree was noted throughout the test and severe scuffing occurred at 4000 r.p.m. Oil consumption was considerably higher and blow-by slightly higher than with the other two cylinders. The temperatures of Cylinders *B* and *C* seem to be well within safe limits because scuffing or distortion was not apparent in either cylinder. The temperatures of Cylinder *C* appear to be almost ideal, and the performance data establishes a basis for forming this conclusion. (See Table 1.)

The search for ways and means for eliminating excessive cylinder temperature is research problem number one in many laboratorics. The problem has been and is receiving considerable attention, but not more than the seriousness of the

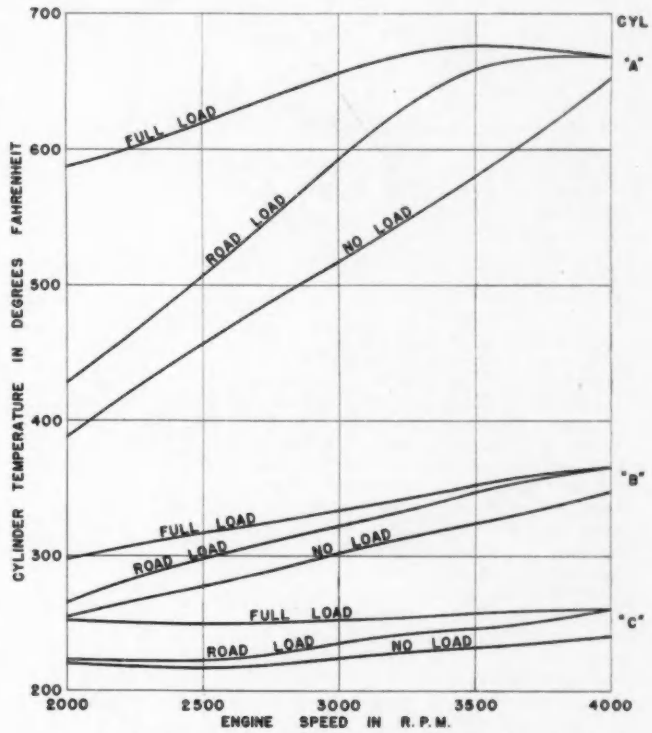

Fig. 3 – Surface Temperatures of Three Water-Cooled Single Cylinders

A—Conventional water circulation.
B—Cylinder *A* redesigned with improved water circulation around and between the valves.
C—See Fig. 4 for design details.

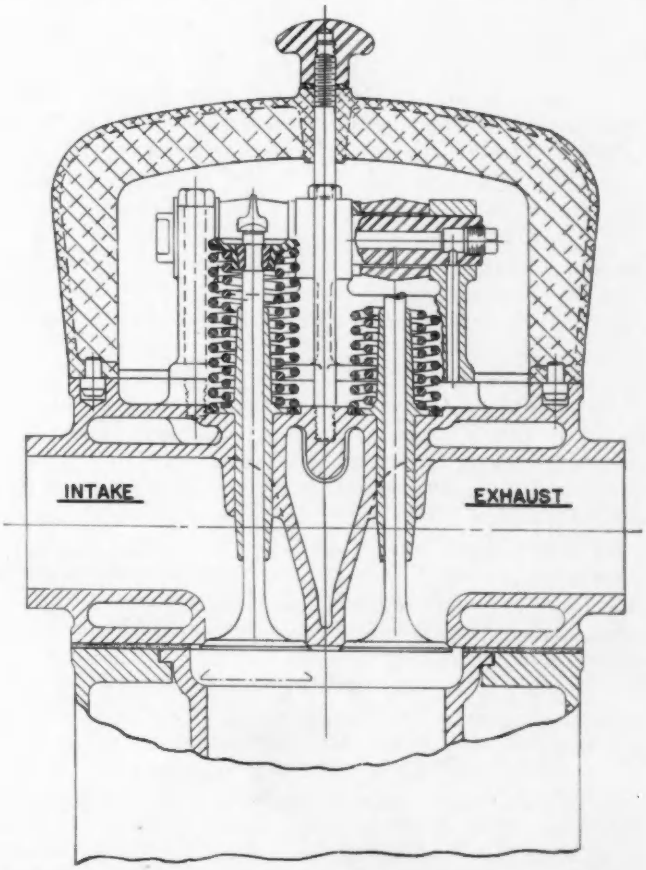

Fig. 4 – Section of Cylinder *C* Showing Details of Sleeve Construction

Table 1 – Performance Data and Engine Specifications

	Cylinder *A*	Cylinder *B*	Cylinder *C*
Oil Consumption at 2500 R.P.M., Road Load, gm. per hr.	13.75	4.5	2.75
Oil Consumption at 3250 R.P.M., Road Load, gm. per hr.	138.0	18.0	12.0
Blow-By at 2500 R.P.M., Full Load, cu. ft. per min.	0.17	0.16	0.16
Blow-By at 3500 R.P.M., Full Load, cu. ft. per min.	0.26	0.19	0.16
Bore and Stroke, in.	3½x5	3½x5	3½x5
Displacement, cu. in.	48.1	48.1	48.1
Compression Pressure at 1000 R.P.M., lb. per sq. in.	133	134	137
B.Hp. at 3500 R.P.M.	10.59	13.0	13.3
F.Hp. at 3500 R.P.M.	12.55	12.60	12.85
I.Hp. at 3500 R.P.M.	23.14	25.60	26.15
Torque at 3500 R.P.M., ft. lb.	15.89	19.63	19.96
Indicated Torque at 3500 R.P.M., ft. lb.	34.72	38.41	39.24
B.M.E.P. at 3500 R.P.M., lb. per sq. in.	49.82	61.54	62.58
Indicated B.M.E.P. at 3500 R.P.M., lb. per sq. in.	108.82	120.42	123.02
Water-In Temperature at 3500 R.P.M., deg. fahr.	160	158	157
Water-Out Temperature at 3500 R.P.M., deg. fahr.	165	166	165
Oil Temperature at 3500 R.P.M., deg. fahr.	182	183	182
Intake Open, deg. before top-center	10	10	10
Intake Closed, deg. after bottom-center	45	45	50
Exhaust Open, deg. before bottom-center	45	45	50
Exhaust Closed, deg. after top-center	10	10	10
Area Intake, sq. in.	1.53	1.53	1.46
Area Exhaust, sq. in.	1.25	1.25	1.46

situation would indicate was necessary. Some progress already has been made and, from indications here and there, better control of cylinder temperature is removing many troublesome difficulties that have been retarding progress.

Design of Two-Engined Aircraft

(Continued from page 327)

speeds almost exclusively it is well to study closely the 62.5 per cent power curves. Here we see that, as we reduce the wing area, the gain in speed becomes less and less so that, with a wing loading of 30 lb. per sq. ft., all of the curves are practically horizontal, especially the 20,000-ft. curve. This relation indicates that, for this type of plane and using this power, there is little to be gained going beyond 30 lb. per sq. ft. To manufacturers who look for higher speeds through a decrease in wing area this would be a point well worth studying. In the lower right-hand corner of Fig. 5 is shown the effect of a decrease in wing area on the rate of climb, ceiling, and landing speed.

Finally a study was made, using the present Electra airplane without change except to change the gross weight, as is shown in Fig. 6. Again comparing the slopes of the three powers it will be seen that the curves for the 62.5 per cent power cruising condition are steeper than those for the full-throttle condition. This comparison shows that a change in gross weight increasing the wing loading from 10 lb. per sq. ft. to 30 lb. per sq. ft., is more detrimental for cruising speed than for the full-throttle condition. This condition is perhaps more clearly shown in Fig. 7. Note the difference in the slopes of the curves.

This study of changes in wing design indicates the thoroughness with which future planes will have to be studied and designed. The items shown in the curves do not amount to a great deal individually but, taken collectively, it is possible that the cruising speed of an airplane could be increased readily by 5 to 10 m.p.h. by proper design of the wing alone.

The remaining problem in the design of twin-engined aircraft which we shall discuss in this paper is the empennage design which, in turn, will be a discussion of stability. For high-speed planes the tail surfaces should be cantilever without bracing of any kind. There is no reason why tail surfaces should be braced with struts or wires. Tail surfaces are in reality small wings and, if designed as such, need no external bracing.

All manufacturers of bimotor aircraft have had difficulty with the problem of stability. With nacelles in the wing it is not possible to use such rear-ward centers of gravity as are possible without the nacelles. It is usually best not to use a center of gravity farther aft than 30 per cent. Due to the distribution of the load in the Electra the center-of-gravity travel was high and additional stability was needed which was obtained through the use of the twin fins and rudders acting as end plates. Fig. 8 shows the increase in the slope of the moment curve due to the addition of the fins and rudders as end plates. Calculations show that the effect of the end plates was to increase the aspect ratio from 4.3 to an effective aspect ratio of 6.3. With this increase in stability it was possible to obtain an approved center-of-gravity travel of from 18.4 per cent to 33.7 per cent with satisfactory results.

To show the very detrimental effects of the nacelles let us look at Fig. 9. With the engine and nacelles completely removed note the slope of the moment curve. This stability would not only be satisfactory but probably the plane would be too stable. However, when the nacelles were put in place the moment curve acquired a very bad hump as shown on the curve marked *Test 1*. This arrangement was decidedly unsatisfactory and was eliminated.

In bimotor design it is best, due to the detrimental effect of the nacelles in the wings and the injurious effect of power-on, to keep the slope of the moment curve at least -0.18 to -0.20 and to keep the center of gravity ahead of 28 per cent and aft of 19 per cent. If these values are followed and the nacelles are designed properly, the problem of instability will not be encountered.

In closing, may I state that the main problem in the design of high-speed bimotors and all other high-speed craft is the elimination of drag by keeping everything out of the air-stream. If determined to do this job from the first, the designer will not find it difficult. Then, by taking advantage of all the fine points in aerodynamic design, he will have an airplane that will always be a little faster and a little better than his competitors.